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DEVELOPMENT OF LIGHTWEIGHT (COLD-WET) INSULATED FOOTWEAR

ARMY NATICK LABORATORIES

JULY 1973

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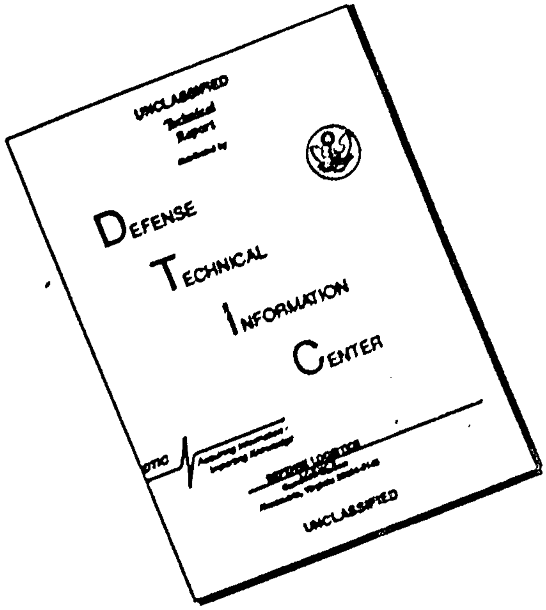

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The first generation of what may be considered a new concept in lightweight insulated military footwear in a pull-on type construction was produced by integrally casting and expanding liquid polyurethane systems.

The footwear developed meets the original requirements established under this program to develop a lightweight impermeable boot with insulation sufficient to provide protection for 2 hours inactivity at -20°F. The average weight of a size 10 boot is 24 ounces, as compared with 44 ounces for the standard (Black) insulated Cold-Wet Boot. The water absorption of the new footwear is less than 5 percent by weight.

The insulative properties of the lightweight integrally cast polyurethane footwear when new are equal to or better than the standard insulated cold-wet boot; there is no significant change in insulative properties after wear.

The developed laboratory procedures were used to design and put into operation a pilot plant facility. Initial production of footwear indicates that the economics and processes involved may be satisfactory for the final commercialization of this new concept of lightweight insulated footwear.

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Cellular Plastics			10			
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TECHNICAL REPORT

73-15-CE

DEVELOPMENT OF LIGHTWEIGHT (COLD-WET) INSULATED FOOTWEAR

by

Joseph E. Assaf

Project Reference:
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July 1973

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Clothing and Personal Life Support Equipment Laboratory
U. S. ARMY NATICK LABORATORIES
Natick, Massachusetts 01760

FOREWORD

Defense commitments necessitate increasing the mobility of the combat soldier while providing him with maximum environmental protection. The physical properties and thermal adequacy of the standard black insulated boot for cold-wet use have been validated by actual field experience. These properties were achieved at the expense of weight (each boot weighs between 40-44 ounces). In reference to energy consumption of the combat soldier, studies indicate that one ounce of weight carried on the foot is equivalent to six ounces carried on the back of the combat soldier (two 40-ounce boots are equivalent to 30 pounds). In view of this information, the development of a new concept for producing lightweight insulated footwear, while retaining other required physical properties, becomes essential.

This report summarizes the work performed in the development of durable, flexible, lightweight, insulated footwear in a pull-on type construction weighing approximately 24 ounces per boot in size 9 with insulation sufficient to provide protection for 2 hours inactivity at -20°F. Under the supervision of the author as Project Officer, materials research studies, development of production procedures and the production of prototype lightweight insulated boots by the integrally cast technique were performed by Uniroyal, Inc. In addition, sectional calorimeter copper foot studies, climatic chamber evaluation and determination of physical property characteristics were carried out at U. S. Army Natick Laboratories and limited research Arctic field tests were conducted in Alaska, all under the monitorship of the author.

The author wishes to acknowledge the valued suggestions offered by Dr. Malcolm C. Henry, Deputy Director of Clothing and Personal Life Support Equipment Laboratory (C&PLSEL), and the aid and guidance of Mr. Douglas S. Swain, Footwear Technologist, also of C&PLSEL, relative to design considerations. The author also wishes to thank Dr. Ralph F. Goldman and Mr. F. Compagnone of the U. S. Army Research Institute of Environmental Medicine (ARIEM) at Natick for conducting the copper foot studies and for their recommendations; and Dr. Harold O. Kiess and Mr. John M. Lockhart, Pioneering Research Laboratory (PRL), for conducting the Climatic Chamber study. He wishes to thank the members of the Rubber Technology Group, C&PLSEL, for their assistance in the evaluations of boots and boot materials.

The work was conducted under DA Project 1J662713DJ40-01, Energy Conservation through Lightweight Clothing and Equipment Systems.

CONTENTS

Page

Appendices

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES (Cont'd)

ABSTRACT

The first generation of what may be considered a new concept in lightweight insulated military footwear in a pull-on type construction was produced by integrally casting and expanding liquid polyurethane systems.

The footwear developed meets the original requirements established under this program to develop a lightweight impermeable boot with insulation sufficient to provide protection for 2 hours inactivity at -20°F. The average weight of a size 10 boot is 24 ounces, as compared with 44 ounces for the standard (Black) insulated Cold-Wet Boot. The water absorption of the new footwear is less than 5 percent by weight.

The insulative properties of the lightweight integrally cast polyurethane footwear when new are equal to or better than the standard insulated cold-wet boot; there is no significant change in insulative properties after wear.

The developed laboratory procedures were used to design and put into operation a pilot plant facility. Initial production of footwear indicates that the economics and processes involved may be satisfactory for the final commercialization of this new concept of lightweight insulated footwear.

FINAL DEVELOPMENT OF LIGHTWEIGHT (COLD-WET) INSULATED FOOTWEAR

1. Introduction

Previously completed materials research studies, processing techniques and fabrication of a limited number of experimental lightweight insulated footwear exceeded initially established goals and indicated that it is possible to provide significantly lighter weight insulated boots without decreasing the effectiveness of the insulation value over that of the current standard black insulated U. S. Army boot which was designed for cold-wet wear.

The standard black cold-wet insulated footwear weighs approximately 40-44 ounces per boot. In reference to energy consumption of the combat soldier, studies indicate that one ounce of weight carried on the foot is equivalent to 6 ounces carried on the back of the combat soldier (two 40-ounce boots are equivalent to 30 pounds).

The data previously developed both in-house[1] and under contract,[2,3] which included the development of formulations, processing techniques, mold design, footwear design, actual production of prototype footwear including materials evaluation, and laboratory and limited field evaluation of experimental boots, were used as the initial starting point for the continuation of the development of the required lightweight insulated footwear. The work covered in this report was based upon the conclusions reached and the trends established by the previous work and continued from that point.

2. Development of Current Standard Insulated Footwear

The principle of the current standard insulated boot was conceived during World War II. The resultant development of design and fabrication methods saw the production of insulated footwear for use in the Korean War. For the first time, a soldier's feet were protected from cold injuries under cold-wet conditions.[4]

The results of continual modifications and improvements in materials, design and fabrication techniques since the Korean War are evidenced in the development of specification requirements [5] for an insulated boot for cold-wet use. This boot was designed to protect feet from cold injury and frostbite in areas where moisture and cold are critical factors, where the mean monthly temperature ranges between 14°F and 68°F and where temperatures do not fall below -20°F.

The physical properties and the thermal adequacy of the black standard insulated boot for cold-wet use (service down to -20°F) have been validated by actual field experience. These properties were achieved at the expense of bulk and weight - each boot weighs 40-44 ounces.

Efforts were made to increase the efficiency of the standard insulated boot by reducing the weight of the boot, while retaining the required insulation, by removal of some of the marginal components and by attempting to reduce the weight of other boot components. The studies indicated that any weight reductions achieved would be negligible and that conventional footwear materials and design have only limited promise for achieving a significant weight reduction without an undesirable loss of physical and thermal properties.

3. Objective

The objective is to achieve durable, flexible, lightweight, [illegible], insulated footwear weighing approximately 24 ounces per boot in size 8, which is impermeable (water absorption maximum weight gain 5%) and which has adequate thermal insulation to permit service down to -20°F for periods of two (2) hours of inactivity.

The integrally cast technique using polyurethane polymer systems permits a reduction in the number of parts required, as well as the elimination of seams, adhesives, and complex fabricating techniques that could result in weak areas or failure points in boots assembled by conventional fabricating techniques. Boots in a pull-on type construction produced by this method should result in boots that are more reliable from the standpoint of retaining insulating properties, less complex to produce, lighter in weight and lower in cost. In addition, the boots produced by this integrally cast technique may also be superior in areas of fit and flexibility than conventionally fabricated boots in a pull-on type construction.

An extensive review of the work previously completed indicated that the technique of integrally casting or expanding in-place a lightweight insulated boot using polyurethane polymer systems in a pull-on type construction offered the greatest potential for the attainment of the objective. A reduction to practice of the concept of integrally cast expanded polyurethane footwear was achieved and shown to be feasible on a semi-production basis. Limited copper foot sectional calorimeter data and preliminary performance studies indicated that the desired thermal insulation properties for a lightweight insulated boot could be achieved.

However, it was determined that in order to produce a boot to meet the overall objectives by the integrally cast techniques the following had to be accomplished:

a. Improve the low temperature flexibility of the polyurethane materials to provide a more flexible boot.
b. Increase the durability and puncture resistance of the outer skin.
c. Provide additional insulation in areas forward of the ankle and in the heel and sole sections.

d. Improve traction of the outsole.
e. Keep at a minimum the compression set of low density materials.
f. Develop the optimum overall fit that can be achieved with the pull-on type concept.
g. Reduce slippage at the heel and improve donning and doffing characteristics.
h. Finalize processing and fabrication techniques.
i. Develop production procedures.
j. Improve appearance.

4. Materials and Design Studies

Polyurethane compounds for use in producing the various components of lightweight insulated footwear (outerskin, upper insulation, outsole) were developed (see Appendix A for formulation and test data that exhibit the best average properties achieved for each boot component, except the sock-lining). A last and a mold were also designed that should provide a good fitting boot in a pull-on type construction.[6]

a. Materials Studies

Studies using various combinations of polyurethane prepolymers, expanding and curing agents, and plasticizers have resulted in achieving compound properties as follows:

(1) Sprayed Outer Skin

Compounding studies resulted in the development of a low modulus polyurethane skin compound that will allow some stretch in the finished boot when it is donned and doffed at service temperatures down to -20°F. The compound possesses good tear and tensile properties that should result in a durable puncture resistant skin.

(2) Upper Insulation

All of the selected desirable compounds obtained from the evaluation of the outer skin formulations served as a starting point for the preparation of an adequate foam insulation compound. Compounding studies resulted in the development of an insulating material (approximately 13 lb/ft^3) containing approximately 90% closed cells that should provide the required overall physical characteristics including low temperature properties. Control of cell size and compound shrinkage was achieved.

(3) Outsole

The polyurethane outsole compound previously developed used methylene chloride as the expanding agent. The outsole produced provided some [illegible] abrasion resistance; however, the sole was considered to be stiff and at low temperatures the traction was not considered adequate. During the outsole compounding studies, nitrogen was substituted for methylene chloride as the blowing agent. Nitrogen was selected since it allows a greater flexibility in the use of plasticizers thereby producing a more resilient outsole. It has the versatility of producing a closed cell structure at lower densities resulting in the formation of a structure containing a greater number of closed cells over that of other blowing agents. A low modulus, more resilient compound with a density of 25-28 lbs/ft^3 was developed. An outsole produced from this compound had improved low temperature properties and should provide better traction but with reduced abrasion resistance. Actual wear tests were conducted on outsoles produced from this compound.

(4) Outsole Wear Test

Since wear characteristics of the outsole and abrasion resistance are considered to be one of the more critical properties contributing to the overall durability of the finished boots, actual wear tests were conducted prior to initiating design studies and fabrications of prototype boots.

Three types of boots were wear tested in order to determine whether the newly developed low modulus nitrogen expanded compound will be acceptable. These boots are identified as follows:

(a) The standard black (cold-wet) insulated boots weighing approximately 48 ounces each used as the control item.

(b) An existing previously developed integrally cast polyurethane black lightweight insulated right foot prototype with the methylene chloride expanded solid outerskin sole with a chevron design, designated as boot IC-312 weighing 18.2 ounces. (Appendix B).

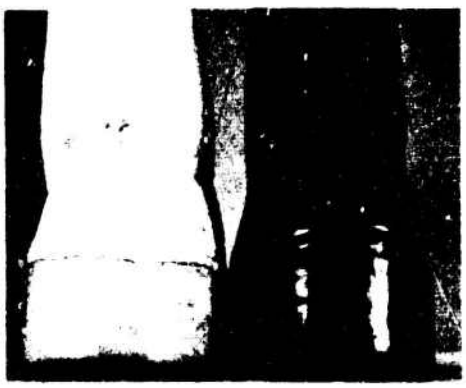
(c) An experimental light-colored boot (left boot) with the newly developed low modulus nitrogen expanded outsole with lug design.*

A 200-mile actual wear test was conducted on all of the boots. The test subject wore the pair of standard insulated boots over a wear course consisting of 90% macadam pavement and 10% concrete pavement for 100 miles and then repeated the wear test using as a pair of boots the previously developed IC-312 right foot prototype and the experimental left boot with the new outsole. The whole procedure was repeated for the second hundred miles. At the completion of the 200 mile wear test, the boots were inspected visually for the effects of wear as shown in Figure 1 and the percent of wear was determined in Table 1.

* Note: The experimental light-colored boot (left) was produced on the same electroformed molds that were used to produce the previous prototype (IC-312) except that the outsole was cast using the new nitrogen expanded compound.

Heel Wear on Standard
Cold-Wet Boots

Sole Wear on Standard
Cold-Wet Boots



Heel Wear on
Experimental Boots

Sole Wear on
Experimental Boots

FIGURE 1 - 200 MILE WEAR TEST CHARACTERISTICS

Figures 1A and 1B show the effects of 200 miles wear on the back of the heels and on the outsole of the standard cold-wet insulated boots. Figures 1C and 1D show that the black IC-312 boot with the methylene chloride expanded outsole exhibits better wear characteristics at both the heel and sole areas than the light colored nitrogen expanded new outsole. However, both lightweight outsoles exhibit better wear characteristics than the outsole on the standard cold-wet insulated boot. Based upon the results of the wear test, it is anticipated that the newly developed nitrogen expanded low modulus, more resilient outsole should provide adequate wear characteristics at the required service temperatures, and should increase traction over that of the methylene chloride outsole, but with some reduction in abrasion resistance.

Wear tests were conducted on the outsoles because there are no standard laboratory abrasion test methods that will provide an indication of the wearing qualities of an expanded compound in actual use. Wear tests will continue to be required until some type of comparative abrasion test can be developed for cellular footwear. It should be noted that any time the standard (cold-wet) insulated boot is used as a control or physical data is obtained on the standard boot, this data is being used only as a guide in the development of the new lightweight insulated footwear.

TABLE I

200 MILE WEAR TEST

Percent Wear*				
Standard Boots			Lightweight Boots	
			Experimental	IC-312
Area	Left	Right	Left	Right
Ball	15	15	25	10
Heel	30	30	20	7
Outer Edge of Heel	60	60	25	10

*Based on measurements of heel and of cleat height in the ball of the foot area, before and after wear.

b. Design Consideration

Since the newly developed formulations for use as upper insulation and outer skin compounds would have some elastic stretch, it was planned to design a last and mold that would provide a fairly tight fit in the boot opening above the ankle area; the object being to reduce to a minimum any possible slippage that may occur at the heel while walking, without significantly affecting don and doff capabilities of a boot produced in a pull-on type construction. The thicknesses necessary to provide the required insulation in the various critical areas of the boot had to be determined. In addition, the optimum traction that would be obtained in the outsole had to be achieved.

(1) Closure Design Study

Prior to continuing the design studies related to a pull-on type construction, a review of closure design studies was conducted. During the engineering design phase of the lightweight footwear previously completed, prototypes were constructed by conventional methods in order to evaluate various types of closures along with the basic pull-on type concept. The closure design studies were necessarily guided by the major objectives of lightweight, low water absorption, and adequate thermal insulation.

Slide fastener closures on the back and side of the boot, snap steel closures and an adjustable buckle and strap attached to the top portion of the boot were evaluated. The closures were designed in an attempt to anchor the boot firmly enough to the foot so that all possibilities of slippage and shucking at the heel would be eliminated for foot comfort while walking, and to provide ample room in the leg-ankle area for ease of donning and doffing.

Figure 2 shows a conventionally hand-assembled boot insulated with polyurethane foam, with a fold-over snap-steel type closure fabricated on the side of the boot. The steel closure was equipped with a swivel on the bottom which allowed the closure to open while donning the boot and to then snap close by itself.

The fold-over area required to form the pocket of the snap-steel closure was insulated. The concept was that the snap-steel closure would be kept closed through the action of the trouser leg drawstring when the trouser legs were pulled down over the boot.

Zipper closures in various areas of the boot such as the back or over the ankle were considered. Figure 3 shows a prototype boot constructed by conventional methods with a zipper closure. The boot materials were not flexible enough to allow adequate take-up when the zipper was pulled closed. Complex fabrication techniques were required to insure reliability of insulation properties.

FIGURE 2 - CONVENTIONALLY ASSEMBLED BOOT WITH FOLDOVER SNAP STEEL CLOSURE

FIGURE 3 - CONVENTIONALLY ASSEMBLED BOOT WITH ZIPPER CLOSURE

Although the insulation values obtained with this footwear were adequate, the additional weight required to produce a reliable insulated closure was considered excessive, and boots produced with closures of this type would require complex fabrication techniques. Therefore, it was determined to remain with the basic pull-on type construction without built-in closures.

(2) Determination of Insulation Thickness

The insulation provided by the standard cold-wet insulated boot in the critical areas of the toe and heel may be considered marginal, and the minimum that can be tolerated. Therefore, the new prototypes to be developed will be designed to provide an increase in insulation over that of the current standard boot. This additional insulation may also be required to compensate for any wear and compression set that may take place at the flex points of any new prototypes produced.

In order to provide guide-lines in determining proper insulation thicknesses, sectional insulating values were measured on the copper foot calorimeter (7) for the standard boot, and for the previously wear tested boot IC-312, when new and after the first 100 miles wear test. Based upon the data obtained, a rigid polyurethane mold was fabricated. This mold was used to construct a crude prototype boot (XP-1) with overall increased insulation thicknesses. Significant increases in thickness were made in the toe, ankle and heel area. The outsole of this crude prototype was makeshift and applied to the upper by hand in order to have a complete boot for obtaining sectional insulating values on the copper foot calorimeter. Although the crude prototype was not representative of the final formulations and the processing techniques used, it was produced to provide some comparison of the sectional insulating values obtained to other boots whose insulation thicknesses and overall insulation values were known (such as boot IC-312) prior to constructing an aluminum mold. Table II presents the sectional copper foot data on all three boots and the sectional thicknesses on boot IC-312 and XP-1. The shape and location of the test zones on the sectional foot calorimeter are shown in Figure 4.

Further evaluation of the data presented in Table II indicated that the ankle, foresole and sole sections (6-18, 11-23, 12-24) of Boot IC-312 were significantly lower than the standard boot and that an increase in insulation thickness was required. After 100 miles of wear, Boot IC-312 showed a change in insulating values in the three sections marked with an asterisk (the tongue and inner and outer instep). The values differ by more than 10 percent from the original. A ten percent change in insulating properties as determined by the copper foot evaluation may be considered significant. The tongue area (section 7-19) showed a loss in insulating values while the inner and outer instep (sections 8-20, 9-21) exhibited an increase in insulating values.

A visual inspection of the tongue area (section 7-19) of the wear tested boot showed that this area exhibited parallel radiating lines along the flex areas and a slight compression set which may account for the loss in insulatinn. Although this loss in insulation may be considered significant, it is not considered critical since the insulation value remains higher than was obtained on the standard 44-oz. boot. However, it does indicate that, during the life of this type of insulated footwear, compression set may become a factor.

TABLE II

SECTIONAL COPPER FOOT CALORIMETER DATA

Foot Sections	Standard Cold-Wet Boot KR-US 6-66 44 ozs	IC-312 18.2 ozs New		IC-312 After 100 Miles Wear	XP-1 (20 oz) Prototype	
	CLO*	Gauge-Mlls	Clo.	Clo	Gauge Mlls	Clo
Overall	1.76		1.89	1.89		2.44
3-15 Ankle Top	1.27	70	1.62	1.53	125	1.60
4-16 Achilles	1.54	250	1.60	1.69	500	2.14
5-17 Heel	1.90	300	1.84	1.90	500	2.78
6-18 Ankle	2.01	150	1.78	1.81	500	2.78
7-19 Tongue	1.32	600	2.09	1.31*	1000	2.92
8-20 Instep (inner)	2.63	300	2.27	2.45*	750	3.50
9-21 Instep (outer)	2.36	300	2.06	2.29*	750	3.50
10-22 Toe cap	1.70	700	2.07	1.96	1000	2.88
11-23 Foresole	2.47	500	1.88	1.97	500	1.87
12-24 Sole	2.73	500	2.27	2.21	500	2.27

*Clo: The amount of insulation necessary to maintain in comfort a sitting, resting subject in a normally ventilated room (air movement 20 ft/min) at a temperature of 70°F and a humidity of air which is less than 50 percent. A difference of 0.1 Clo is considered significant.

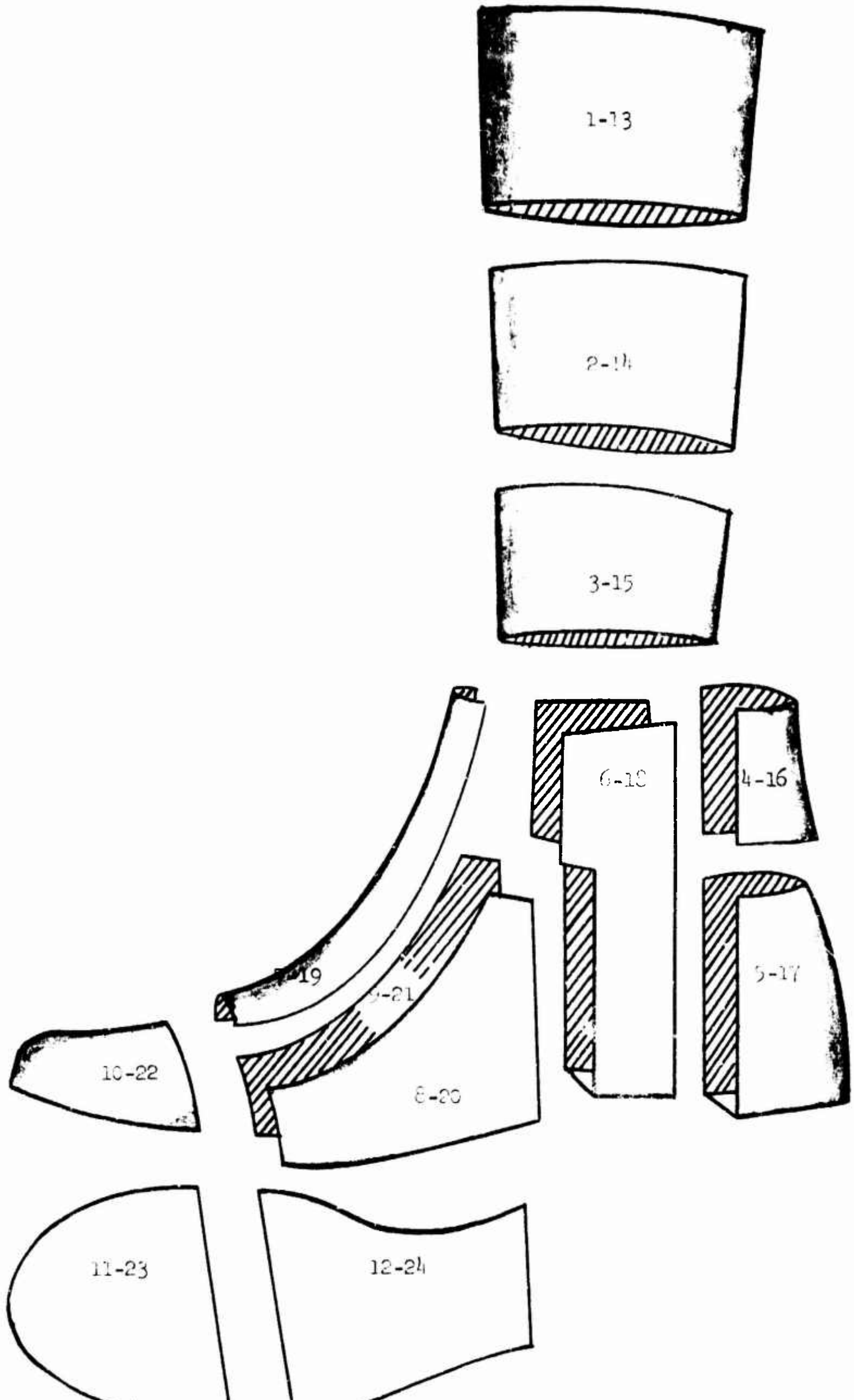


FIGURE 4- COPPER FOOT TEST ZONES (SCALE 1:2-1/2)

A visual inspection of the inner and outer instep (sections 8-20, 9-21) located immediately below the tongue area indicated that a slight delamination of the skin from the insulating foam had taken place, possibly resulting in some trapped air between the skin and the insulating material, which may possibly account for the insulation gain in these sections.

The copper foot calorimeter data obtained on boot XP-1 is significantly superior to both the standard cold-wet boot and to Boot IC-312 except in the sole and foresole areas. As previously discussed, there was no effort made to increase outsole insulation in the experimental boot (XP-1) and a make-shift outsole was applied in order to have a complete boot for test. The primary purpose was to determine the clo values in the critical areas in the upper sections of the boot. The insulation values for sections (8-20, 9-21) match the highest values for the sections ever recorded on the sectional foot calorimeter.

Based upon the increase in thickness that was required to achieve the superior insulation properties, certain critical factors have to be taken into consideration: the effect of increased thickness of insulation on (1) low temperature flexibility; (2) compression set; and (3) flex characteristics when related to flex cracking in the upper section specifically across the toe, above the heel in the back of the boot, and in the ankle area. Taking into consideration these critical factors, it was determined that in order to meet all of the objectives of the finished boot, the insulation thickness must be reduced over that of the thicknesses encountered in the crude experimental boot (XP-1). It was believed that some reduction in insulation thickness would not substantially affect overall insulation properties and that adequate insulation would be retained.

Analysis of the insulation thicknesses in relation to clo values obtained in Table II on the three boots, led to the selection of the proposed thicknesses shown in Figure 5 for the various areas of the boot. These selected thicknesses were to be used in producing the first prototype.

(3) Outsole Traction

In an effort to increase traction characteristics of the newly developed low modulus nitrogen expanded outsole, development and review of various traction patterns were undertaken. Indications were that a Lug type traction pattern, Figure 5, had the potential of increasing the overall traction of the outsole over that of the chevron design previously used. However, it was not known what effect on wear, if any, would take place, since at this time there was no way to determine the wear characteristics of this Lug traction pattern with the specific outsole material.

(4) Fit Studies

Fit studies using the crude experimental prototype (XP-1) indicated that the new ankle design was too tight and would have to be modified prior to producing the aluminum molds. However, the fit in the toe area and across the ball of the foot was considered good.

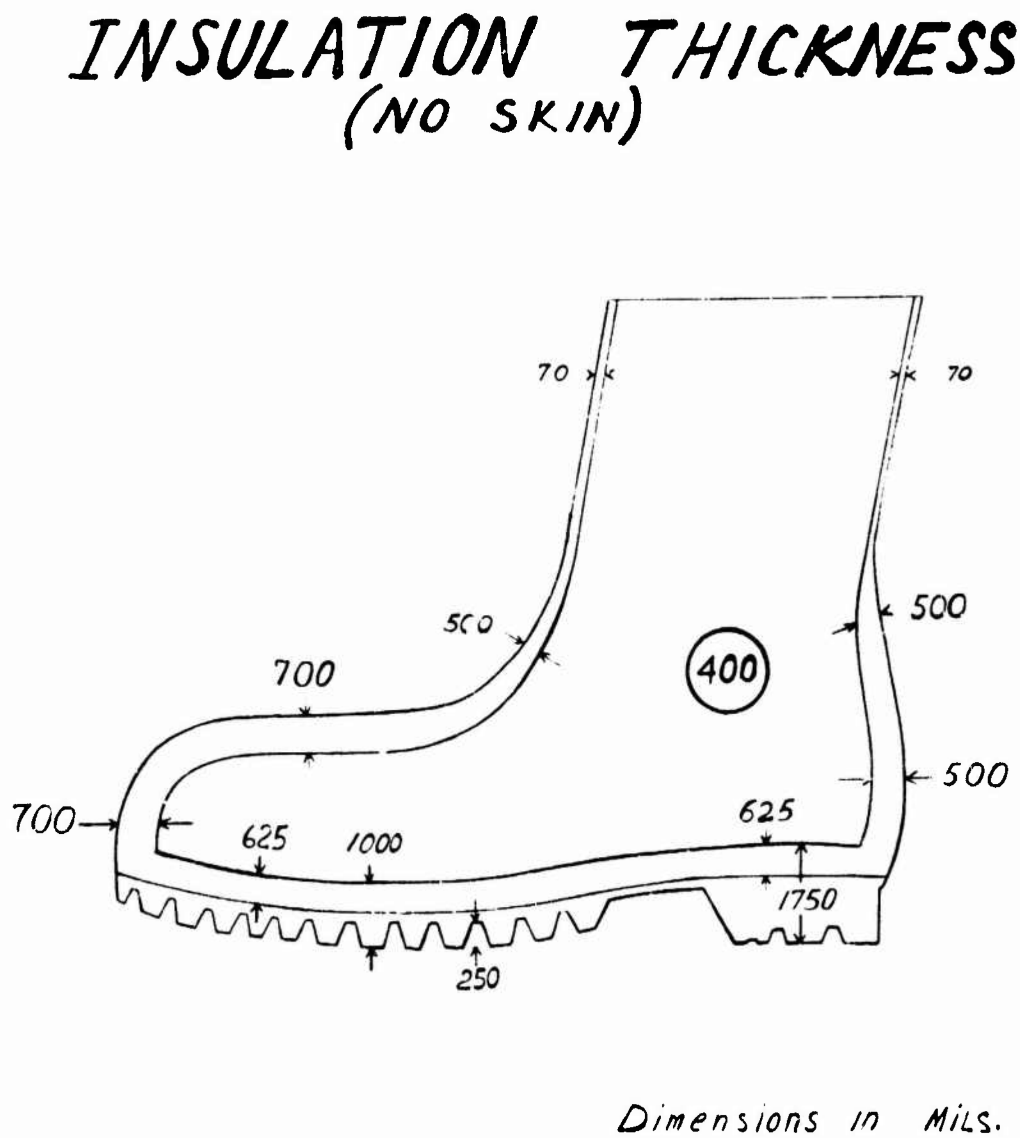


FIGURE 5 - INSULATION THICKNESS (NO SKIN)

(5) Fabrication of Molds

A pair of size 10R lasts and molds were constructed from cast aluminum embodying all of the design considerations, including pull-on type construction, increased insulation as shown in Figure 5, with the Lug type pattern in the outsole for increased traction (Figure 6) and a modified ankle design to keep slippage at the minimum. The mold sections were coated with teflon to eliminate the use of release agents prior to each injection of compound into the mold.

(6) Fabrication and Evaluation of Prototype Footwear

The first pair of prototype footwear in size 10R (designated 3001A & A1) weighing approximately 20 ounces per boot was produced by the integral casting technique embodying all of the optimum characteristics developed under the completed materials and design studies. The pull-on style boot produced was approximately 10.75 inches high and the insulation thicknesses are as shown in Figure 5. The inner lining or sock-lining of the footwear was a 0.010 inch thick film of polyurethane for providing the required slip for donning and doffing. To provide a durable abrasion-resistant exterior the footwear had a sprayed-on black outside solid skin (average thickness 0.020 inches) of polyether-type polyurethane.

The external dimensions of this boot in size 10 were determined and compared to the standard (black) size 10 Cold-Wet Insulated Boot. The results (Table III) indicated that the difference in dimensions between the two boots was minimal.

TABLE III

External Dimensions of the Standard Cold-Wet Insulated Boot and Prototype Boot R-3001-A1.

	Std Cold-Wet (inches)	Proto R-3001-A1 (inches)
Bottom Width (Across Ball)	4-5/8	4-1/4
Upper Width (Ball Area)	4-7/8	5-1/16
Ball Girth	15	14-7/8
Height at ball	3-5/8	3-3/16
Length Overall	12-7/8	12-11/16
Upper Width (at heel breast)	4-1/16	3-15/16

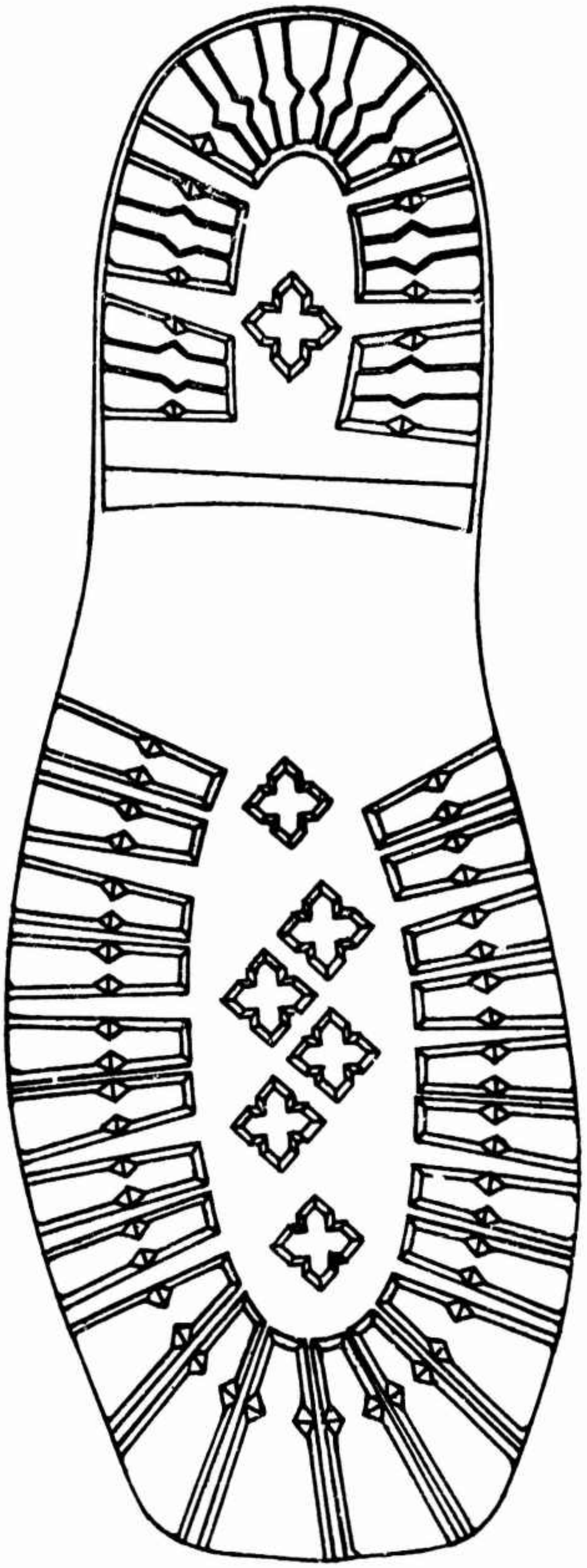


FIGURE 6 – LUG TYPE TRACTION PATTERN

Figure 7 presents a side view of this prototype boot (R-3001A1) and Figure 8 shows the outsole design. Copper foot studies (Table IV) indicated that when new, the insulation characteristics, when compared to the standard insulated boot, were more than adequate. The clo value in the critical areas of the heel, toe-cap and tongue of the prototype boot significantly exceeds the clo value of the standard boot. The prototype boots exhibit a lower clo value than the standard boot in the foresole and sole areas (sections 11-23, 12-24). Since there is no available data that indicates that the lower clo value in the outsole is critical, it was determined to accept these insulation values as adequate. (Most complaints of cold feet have been recorded as being in the toe and heel area.)

TABLE IV

COPPER FOOT CALORIMETER DATA

Foot Sections	Boot Cold-Wet 44 oz KR[illegible]US-6-66	Boot-R-3001-A1 20 oz.
	Clo	Clo
overall values	1.76	1.99
3-15 Ankle top	1.58	1.45
4-16 Achilles	1.70	1.69
5-17 Heel	1.74	2.22
6-18 Ankle	2.19	2.01
7-19 Tongue	1.46	1.91
8-20 Instep (inner)	2.41	2.34
9-21 Instep (outer)	2.22	2.57
10-22 Toecap	1.86	2.28
11-23 Foresole	2.58	2.13
12-24 Sole	2.86	2.39

Based upon these results, six additional pairs of boots were produced for further evaluation prior to continuing the work. The results of this limited evaluation indicated:

a. After several hours of wear, doffing of boots became difficult

FIGURE 7 - SIDE VIEW OF PROTOTYPE R-3001-A1

FIGURE 8 - OUTSOLE DESIGN OF PROTOTYPE R-3001-A1

because the polyurethane spray-film sock-lining apparently did not possess adequate slip characteristics.

b. Wear test data indicated that an adjustment in the processing technique used to produce the outsole was required in order to increase durability characteristics.

c. The puncture resistance of the outer skin required improvement by increasing thickness and by adjustment of the compound application and processing.

d. An increase in the dimensions of the outsole and heel was required to improve durability and to provide better balance to the boot during walking.

e. It was also determined that a square outsole in the toe area would facilitate mountain climbing when necessary.

f. Insulative properties are equal to or better than the standard insulated boot and show no change in insulation characteristics after 200 miles of wear as shown in Table V.

Concurrently with the evaluation of the six pair discussed above, the R-3001-A1 prototype was wear tested. The overall clo value (1.99) of this prototype when new and after 200 miles wear shows no change, and may be considered superior to the overall clo value (1.76) of the standard insulated boot.

The measured values indicating minor increases and decreases of insulation in some areas of the prototype boot after wear, are no more than would be anticipated to occur in the standard insulated boot after wear.

Although 200 miles of wear distance (180 miles macadam, 20 miles concrete) may not be considered significant, it does indicate that there may not be any breakdown in cell structure of the expanded materials in the upper section of the boot as a result of any compression set that may have taken place during wear and, therefore, the life expectancy of the insulation and material characteristics may be considered satisfactory.

A visual examination of the wear tested prototype, R-3001A-A1,(Figure 9) after 100 miles showed that (1) the outerskin had split near the arch of the right boot; (2) although the overall outsole and heel wear was considered to be good, some chunking out of the cleats of the right boot outsole had taken place. The possible cause of these deficiencies in the durability of the outerskin and outsole may be attributed to improper processing techniques during fabrication of the prototype footwear. After the second hundred miles the left boot exhibited a one-inch break across the instep and the outsole showed some wear at the outside edge of the heel and at the ball of the foot. In addition, one cleat in the heel showed some chunking. The right boot exhibited an additional break in the outerskin

TABLE V

COPPER FOOT CALORIMETER DATA

WEAR TESTED PROTOTYPE

Sections	R3001-A1-20 Ounce		
	Initial Clo	100 Miles Clo	200 Miles Clo
Overall Values	1.99	1.99	1.99
3-15 Ankle top	1.45	1.51	1.42
4-16 Achilles	1.69	1.67	1.58
5-17 Heel	2.22	2.28	2.28
6-18 Ankle	2.01	2.05	2.00
7-19 Tongue	1.91	1.83	1.87
8-20 Instep (inner)	2.34	2.26	2.42
9-21 Instep (outer)	2.57	2.61	2.74
10-22 Toecap	2.28	2.12	2.14
11-23 Foresole	2.13	2.11	2.12
12-24 Sole	2.39	2.42	2.49

FIGURE 9 - PROTOTYPE R-3001A-A1 WEAR TESTED 200 MILES

and additional chunking out of cleats. There was significantly less wear noted on the left boot outsole as shown in Figure 9 (200 mile wear test) which substantiates that mixing techniques must be improved and that processing adjustments are required for both the outerskin and outsole formulations to achieve uniformity of wear characteristics and physical properties. However, the overall integrity of the prototype boots was maintained and there was no change in the overall insulation values as shown in Table V.

5. Materials and Design Studies Continued

Based upon the results of the limited evaluation of the prototype (R-3000 series) footwear, extensive materials design (includes last and mold) and processing studies were conducted (6) and additional prototype footwear all in size 10R was produced. Four prototypes were selected for evaluation and are compared to the initial prototype R-3001 in overall weight and modifications in Table VI.

TABLE VI

PROTOTYPE BOOTS SELECTED FOR EVALUATION

	Ounces per Boot Min	Max
PROTOTYPE (R-3001)		
Narrow outsole, Urethane Sock, No counter	19	24
NEW PROTOTYPES		
R-3002 - Wide Outsole, Urethane Sock, No Counter	21	26
R-3005 - Wide Outsole, Urethane Sock, with Counter	22	27
R-3003 - Wide Outsole, Nylon Sock, No Counter	23	28
R-3004 - Wide Outsole, Nylon Sock, with Counter	24	29

The outsoles of all four new prototypes presented in Table VI were cast in a newly designed outsole mold section, which results in a wider outsole and heel with the heel pushed back so that when the upper section of the boot was cast, the edge of the heel was almost in line with the upper and the toe end of the outsole was square rather than round, as shown in Figure 10.

Figure 11 presents Prototype R-3001 with the narrow outsole and the overhang of the upper insulation which is around the outer edge of the outsole, the side, and over the toe area.

Figure 12 compares the wide heel of Prototype R-3003 to the narrow heel of Prototype R-3001.

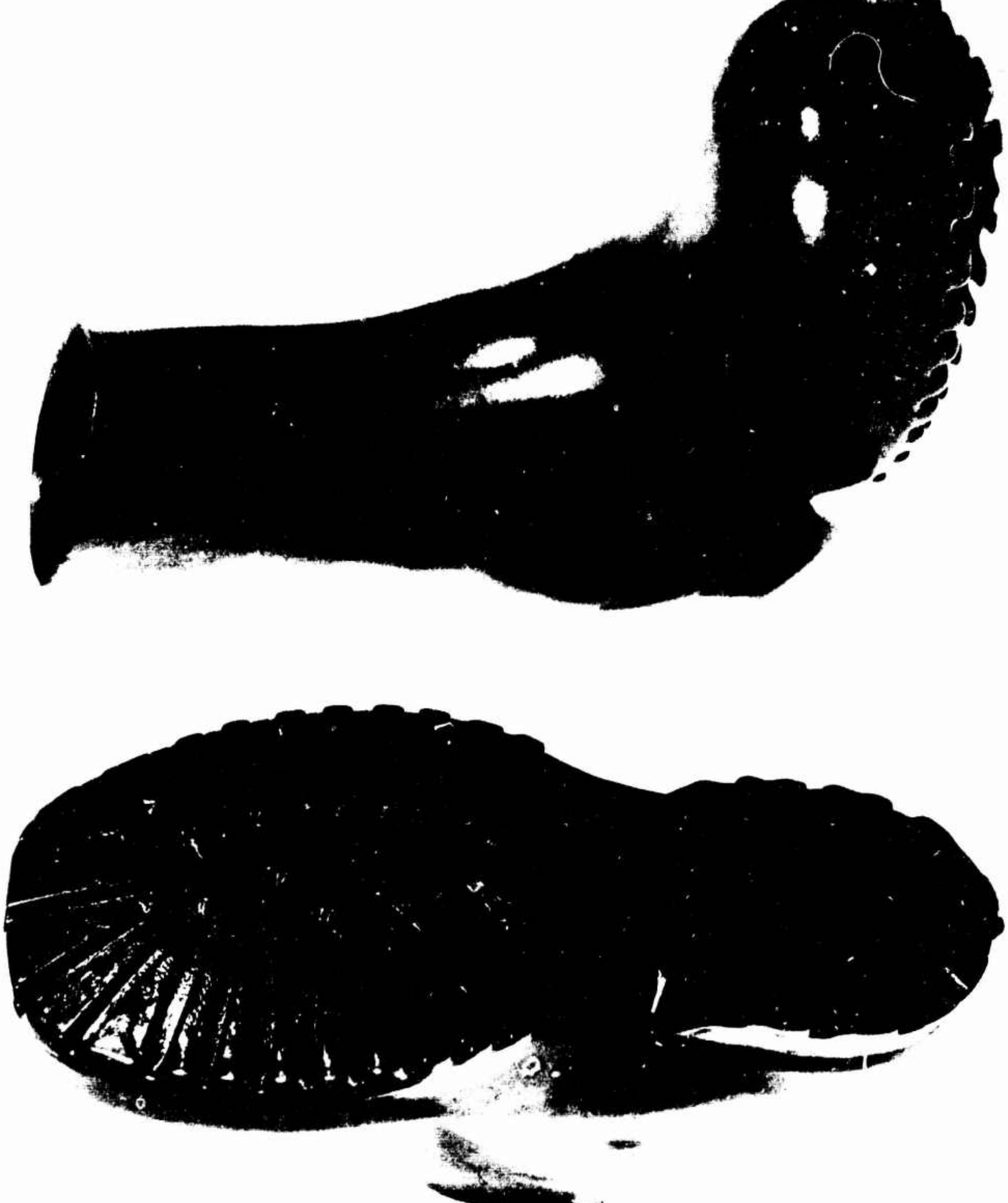


FIGURE 10 - PROTOTYPE R-3003 - WIDE OUTSOLE

FIGURE 11 - PROTOTYPE R-3001 WITH NARROW OUTSOLE

FIGURE 12 - WIDE HEEL OF PROTOTYPE R-3003 (LEFT) COMPARED TO NARROW HEEL OF PROTOTYPE R-3001

Figure 13 shows the square toe and side outsole of prototype R-3003 compared to the round toe and overhang of upper insulation over the outer edge of the outsole prototype R-3001.

A comparison of prototype R-3001 and R-3002 in Table VI shows that the wider outsole, heel and square toe results in an increase of 2 ounces in the overall weight of the outsole. However, this change results in a more balanced boot with increased durability and functionality. In addition, the processing technique for the outsole was modified in an effort to increase wear characteristics.

Table VI also shows that two prototypes R-3005 and R-3004 were produced with expanded heel counters integrally cast with the outsole. The density of the heel counters is approximately 28 lbs per ft.^{3}. The counter was added to render additional support to the heel of the foot and to stabilize the foot so that it would not shift off the edge of the outsole. The expanded heel counter appears to provide slightly better heel support and stability to the foot; however, this slight improvement in support at this time in the development cycle did not justify the increase of one ounce in weight per boot and this approach was not given further consideration. However, it does indicate that the flexibility is present for making significant compound, processing and design changes if required to improve the overall characteristics of the footwear.

The substitution of a nylon socklining in prototype R-3003 for the sprayed polyurethane film socklining in prototype R-3002 results in an increase in weight of about 2 ounces per boot. The nylon socklining was used to improve the slip qualities of the socklining and improve ease of don and doff over that of the sprayed polyester polyurethane film socklining. The nylon socklining consists of a nylon fabric laminated to a cotton fabric with a natural rubber interface which is vulcanized after lamination but before the material was stitched into a sock. The 100% nylon tricot fabric weighs 2.7 ounces per square yard and is used against the foot. The fabric used against the polyurethane foam is a 3 ounce ribbed net cotton. The nylon against the foot provides good slip qualities but has poor adhesion characteristics to the polyurethane; therefore, the cotton fabric is required to obtain good adhesion to the polyurethane foamed upper. The vulcanized natural rubber gum coat (0.006 inch thick) between the two fabrics prevents the liquid polyurethane from coming through to the nylon when the boot is being fabricated and thereby nullifies the good slip properties of the nylon sock.

During the processing studies it was determined that the nylon sock acts as an insulator, and prevents the heat transfer from the last to the compound from being as efficient as the heat transfer from the mold to the compound. Therefore, the overall expansion of the compound is decreased and results in a slightly higher density boot. This higher density results in a 1 or 2 ounce additional increase in the weight of each boot.

FIGURE 13 - SQUARE TOE AND WIDE OUTSOLE OF PROTOTYPE R-3003
COMPARED TO ROUND TOE AND NARROW OUTSOLE OF PROTOTYPE R-3001

To compensate for the insulating effect caused by the nylon sock during processing, the mold and last temperature was increased from 230° to 250°F. Since the mold and last must be heated together, the added heat transmitted by the mold results in over-expansion and the resulting compound was soft and lacked durability. On the other hand, if the mold is not heated to higher temperatures, but rather more blowing agent is added to the compound, the expansion of the compound is more violent and the foam contains many cells which have ruptured, thereby producing an open cell structure. These results indicated that the balance between temperature and blowing agent is critical and in order to maintain optimum compound properties and an adequate uniform cell structure, a slight increase in density and weight over that previously obtained had to be accepted. The increased firmness of the insulation caused by the increase in density of the foam, in combination with the nylon sock-lining, resulted in a slightly tighter fit which had good heel support and resulted in some reduction in slippage at the heel. The nylon socklining increased the ease of don and doff.

The five ounce spread in weight between the minimum and maximum weight of each boot of the same prototype shown in Table VI should be reduced as processing procedures are finalized and production procedures developed that will accurately control time-temperature relationships.

These prototype boots were evaluated on the sectional copper foot calorimeter. Table VII presents the insulation values on all of the four new prototypes developed with the wide outsole and the one with the narrow outsole (R3001 A & A1) and these prototype boots are compared to both the current standard cold-dry and cold-wet boots.

The data on the standard insulated boots is presented for comparative purposes. The standard insulated boot (white) for cold-dry use conforms to the requirements of Type II Class I of Military Specification MIL-B-4186, Boots, Insulated, Cold-Weather, Rubber Type, dated 15 March 1965. This boot has been designed to protect the feet in sub-zero conditions and is worn when actual temperatures of -20°F or below may occur. The physical properties and the thermal adequacy of the standard white insulated boot for cold-dry use (service below -20°F) have been validated by actual field experience. As previously stated the standard black insulated boots are designed to protect the feet from cold injury in areas where the temperature does not fall below -20°F. The new prototypes being developed are to be equivalent in insulation values to the standard black insulated boot for cold-wet use.

A comparison of the insulation values obtained on prototypes R-3002-2 and R-3005-2 (with polyurethane socklinings and with and without heel counters) to prototypes R-3003-2 and R-3004-2 (with nylon socklining and with and without heel counter) shows that the addition of a heel counter does not significantly affect the insulation properties at the heel.

TABLE VII

COPPER FOOT CALORIMETER DATA

Foot Sections	Standard Insulated Boots: Cold-dry 48 oz	Standard Insulated Boots: Cold-wet 44 oz	Narrow Outsole R-3001A1: 20 oz *PS	Wide Outsole: R-3002-2 22 Oz PS	Wide Outsole: R-3005-2 23 oz PS**HC	Wide Outsole: R-3003-2 27 oz ***NS	Wide Outsole: R-3004-2 25.5 oz NS-HC
Overall value	1.94	1.76	1.99	2.14	2.07	1.84	1.88
3-15 Ankle top	1.51	1.27	1.45	1.58	1.57	1.46	1.41
4-16 Achilles	1.56	1.54	1.69	1.91	1.79	1.48	1.51
5-17 Heel	1.90	1.90	2.22	2.41	2.28	2.00	1.92
6-18 Ankle	2.10	2.01	2.01	2.15	2.03	1.74	1.79
7-19 Tongue	1.42	1.32	1.91	2.10	2.13	1.78	2.03
8-20 Instep (Inner)	2.81	2.63	2.34	2.55	2.49	2.17	2.21
9-21 Instep (Outer)	2.24	2.36	2.57	2.75	2.79	2.38	2.59
10-22 Toecap	2.03	1.70	2.28	2.43	2.17	2.07	2.27
11-23 Foresole	2.87	2.47	2.13	2.17	2.03	1.88	1.94
12-24 Sole	3.37	2.72	2.39	2.60	2.44	2.24	2.25

Note: 1. All Boots Size 10R
Note: 2. All values presented are in clo's.

*PS - Polyurethane Socklining
**HC - Heel Counter
***NS - Nylon Socklining

A comparison of Prototype R-3001-A1 (narrow outsole) with polyurethane sock to prototype R-3002-2 (wide outsole) with polyurethane sock, indicated that increasing the width of the outsole increases the clo value in the sole area. There is also a slight increase in insulations in most of the foot sections, which is reflected in a higher overall clo value in prototype R-3002-2.

The substitution of a nylon sock lining (prototype R-3003-2) for the polyurethane sock lining used in prototype R-3002-2 reduces the insulation values in all of the foot sections, resulting in a significant overall reduction in clo value of 0.30 clo.

The lower insulation values obtained on prototype R-3003-2 were caused by the higher densities achieved in both the upper insulation and outsole as a result of having to modify the processing technique in order that the boot be capable of accepting the nylon socklining without adverse affects on other required physical properties. However, the overall insulation values of prototype R-3003-2 (with nylon socklining) is considered more than adequate when compared to the insulation values obtained on the standard insulated cold-wet boot. Prototype R-3002-2 (with polyurethane socklining) exhibits excellent insulation values. The overall clo value of 2.14 exceeds the 1.94 overall clo value of the cold-dry boot which has been designed to protect the feet when actual temperatures of -20°F or below may occur. Because don and doff characteristics were considered critical and since the wide outsole and heel should provide additional durability and stability, prototype pair R-3003-2 (with nylon sock) was selected as the design model for the fabrication of fifty pairs to be used in a limited field research test and evaluation of physical properties. In addition, this production run would result in the optimization of processing techniques and the development of production cycles and quality control procedures. The trade-off of the increase in weight and the lower clo values obtained in prototype R-3003-2 versus the substantial increase in ease of don and doff and additional functional stability was considered desirable. It was anticipated that, during the optimization of the processing techniques and the establishment of production cycles, it might be possible to provide some increase in overall insulation values of prototype R-3003-2 by achieving better control and uniformity of cell size during the expansion cycle of the selected formulations.

Table VIII presents the compound formulations used in producing prototype pair R-3003-1 and 2. These same formulations were to be used in producing the fifty pair of boots for evaluation.

The nylon/cotton fabric laminate material used for producing the socklining has been previously described. A completed socklining in size 10R weighs approximately 2½ ounces per socklining.

TABLE VIII

FORMULATIONS FOR PROTOTYPE R-3003-1 and R-3003-2

Outsole	PHR
Vibrathane B-602	100
Santicizer S-140	25
mPDA	4
Santicizer S-160	4
SF-1079 Silicone	2
Nitrosan	0.7
US-15N	0.7
3041 Black	2.1
Upper	**PHR**
Vibrathane B-602	100
Santicizer S-140	25
mPDA	4
Santicizer S-160	4
SF-1079 Silicone	2
Nitrosan	7
US-15N	3
Outer Skin	**PHR**
Vibrathane B-605	100
Toluene	200
mPDA	3.8
THF	51.2
Santicizer S-160	40
3041 Black	5

The insulation thicknesses of prototype pair R-3003 without the outer spray skin are presented in Table IX. These dimensions are the same as presented in Figure 5.

Table IX

INSULATION THICKNESS OF PROTOTYPE BOOTS R-3003

NO SKIN

Upper Insulation Thickness*

	Side	Front	Back
Top Edge	70	70	70
Ankle	400	500	500
Heel	---	---	500
Instep	600	600	---
Toe	700	700	---

Outsole Thickness* (Includes cleats which are 250 mils thick)

Heel	175.0
Arch	750 (No cleats)
Ball	1000

*Thickness in Mils

Although prototype R-3003 was selected for the production of fifty (50) pair of lightweight insulated footwear for evaluation of durability in the field and determination of physical properties, an additional two (2) modified R-3003 prototype pairs were fabricated in the event that the research field tests to be conducted might indicate that modification would be required to improve the functionality, comfort and durability of prototype R-3003 as presented.

The two (2) additional prototype pairs produced are identified and described as follows:

Prototype Pair R-3007-1,-2

Prototype pair R-3007-1,-2 shown in Figure 14 is identical to prototype pair R-3003-1,-2 except that a three inch high nylon snow collar with a draw lace at the top was attached to each boot. The snow collar was added to seal off the top of the boots if required to reduce heat loss and preclude snow entering the boot through the open top. The snow collar was fabricated from the same material used to fabricate the socklining.

FIGURE 14 - PROTOTYPE PAIR R-3007

Prototype Pair - R-3008-1,-2 is identical to prototype pair R-3003-1,-2 except that the outsole design was changed from the Lug type as shown in Figure 6 to a newly developed design E presented in Figure 15. The selection of design E was based upon the results of studies of various outsole designs. In the event that increased outsole wear characteristics may be required in prototype R-3003, outsole design E increases the wear surface dimensions of the outsole in the area of the ball of the foot that comes into contact with the ground over that of the Lug type design shown in Figure 6. This should result in increased wear characteristics and in addition the transverse center cleats serve to distribute the weight over a larger area.

6. Mold Description

Figures 16 and 17 present photographs of the actual last and mold sections and show the overall mold assembly being held together in a jig. The overall mold for each boot consists of five (5) pieces and a last. One of the pieces is a sole plate containing two (2) other pieces which are side rings and form the upper edge of the outsole when the last is rested on the rings. The last is a U.S. MIL-V Combat Boot Last modified to reflect the design changes required to provide good fit for a boot of pull-on type construction in size 10R. The parts as numbered in the photographs are described as follows:

1. Sole plate

2. and 3. Sole plate side rings

4. and 5. Upper mold sections

After the outsole is molded, the side rings are removed and the two other pieces (upper mold sections) which form the boot upper are brought together around the last which is still in the same position it was when the outsole was formed.

The molds are fabricated from cast aluminum and have a permanent teflon coating to insure ease of demolding completed footwear.

Figure 18 is a schematic showing sole molding and upper section molding and location of injection port. For purposes of illustration it shows the sole in place with the sole plate dropped. However, during the actual molding cycle, the sole plate remains in place until the finished boot is demolded.

7. Procedure for Producing R-3003 Prototype Footwear

Accurate time and temperature control of equipment, compounds, and processing during the molding cycle is required to achieve proper densities and adequate physical characteristics.

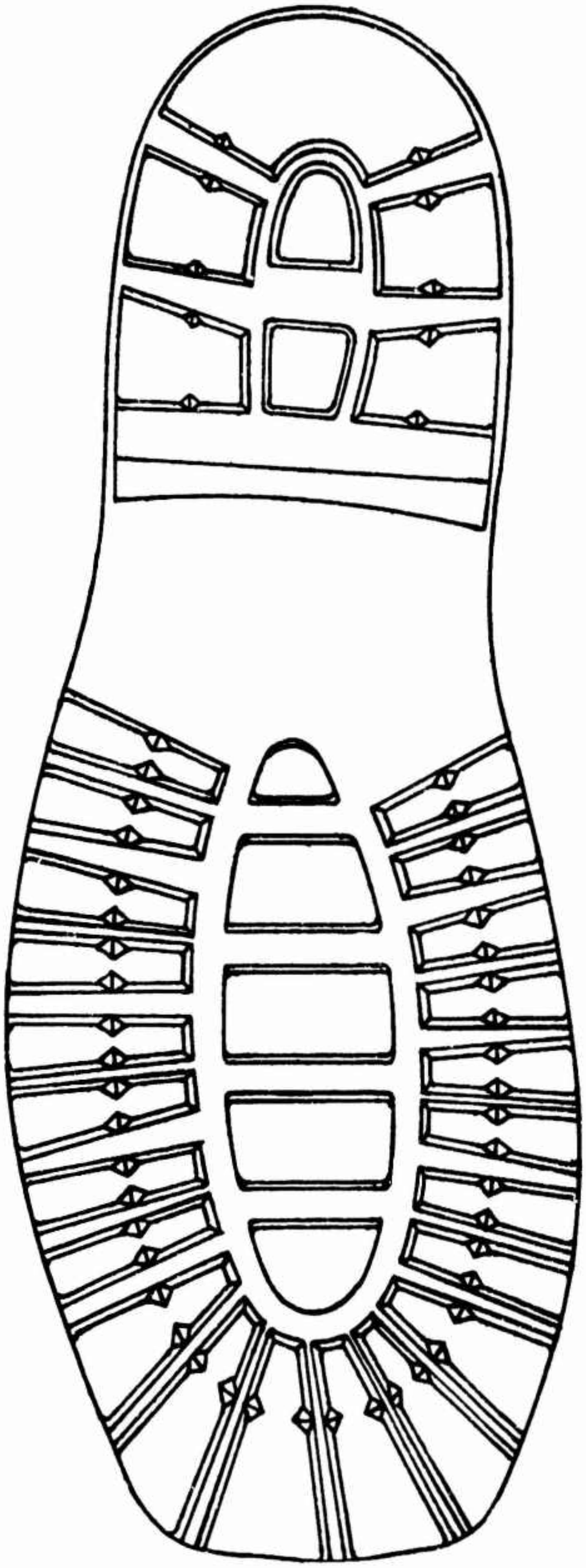


FIGURE 15 - OUTSOLE DESIGN E

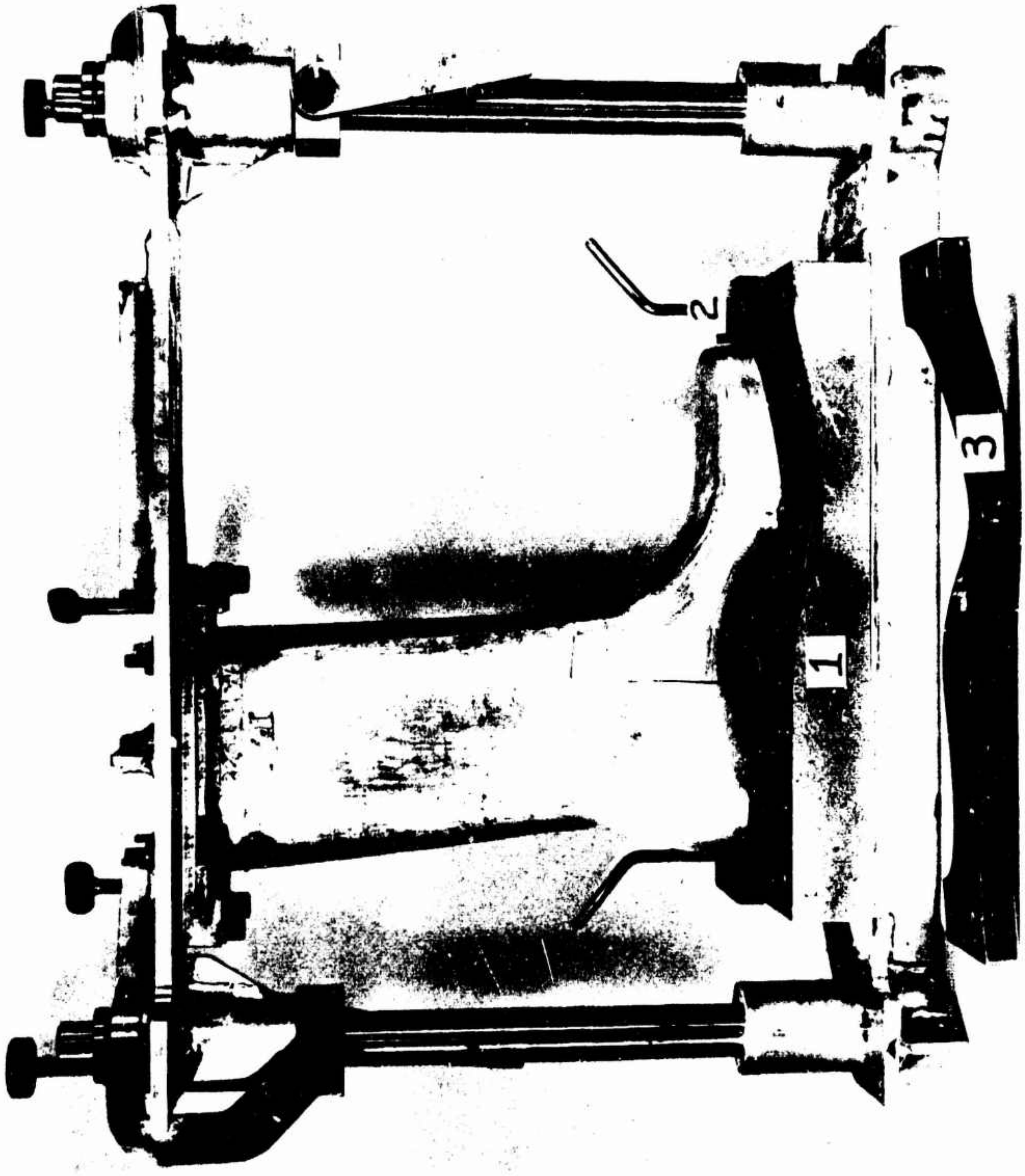


FIGURE 16 - IDENTIFICATION OF MOLD SECTIONS

1 - Sole Plate 2 and 3 - Sole Plate Side Rings

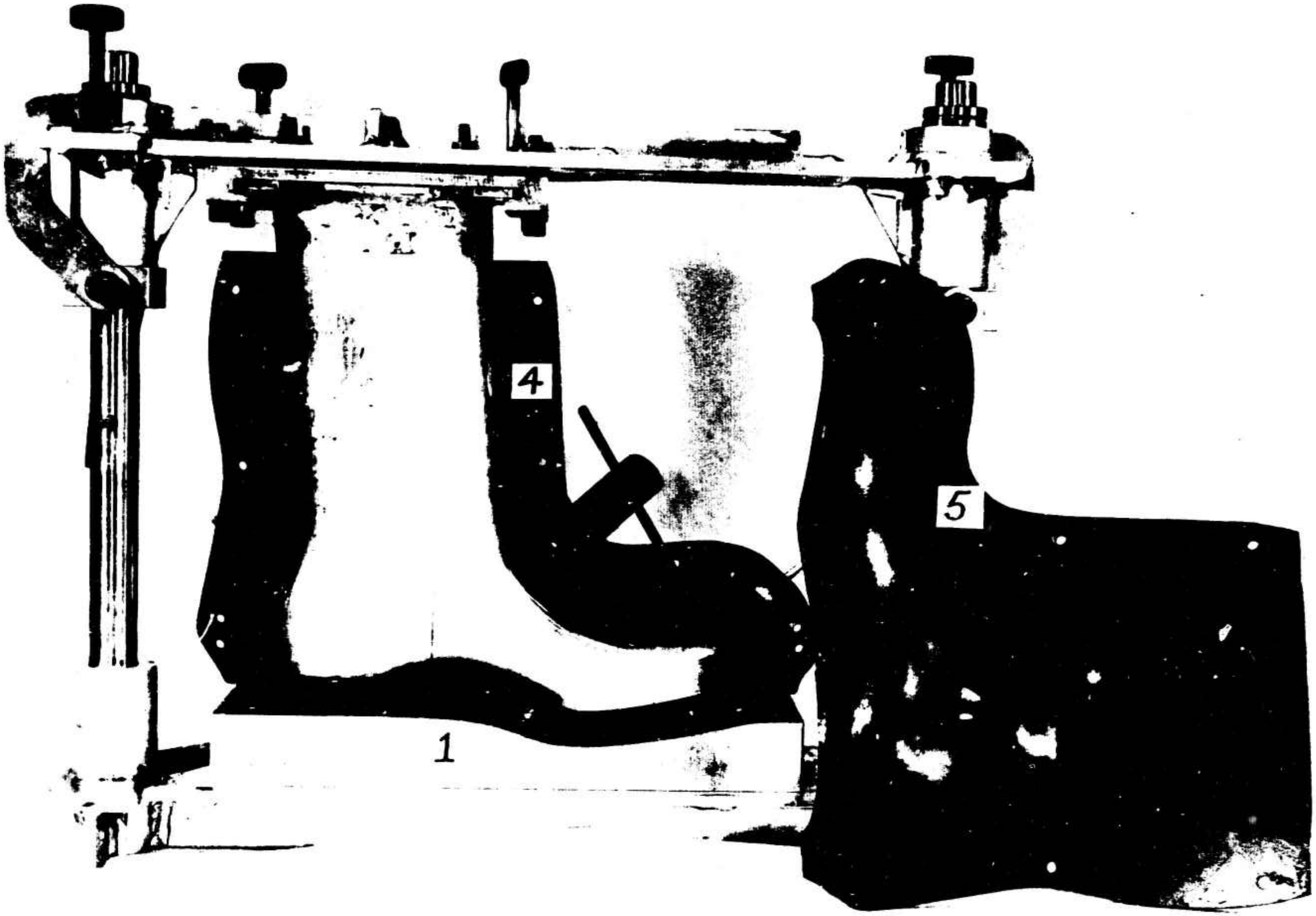


FIGURE 17 - IDENTIFICATION OF MOLD SECTIONS

1 - Sole Plate

4 and 5 - Upper Mold Sections

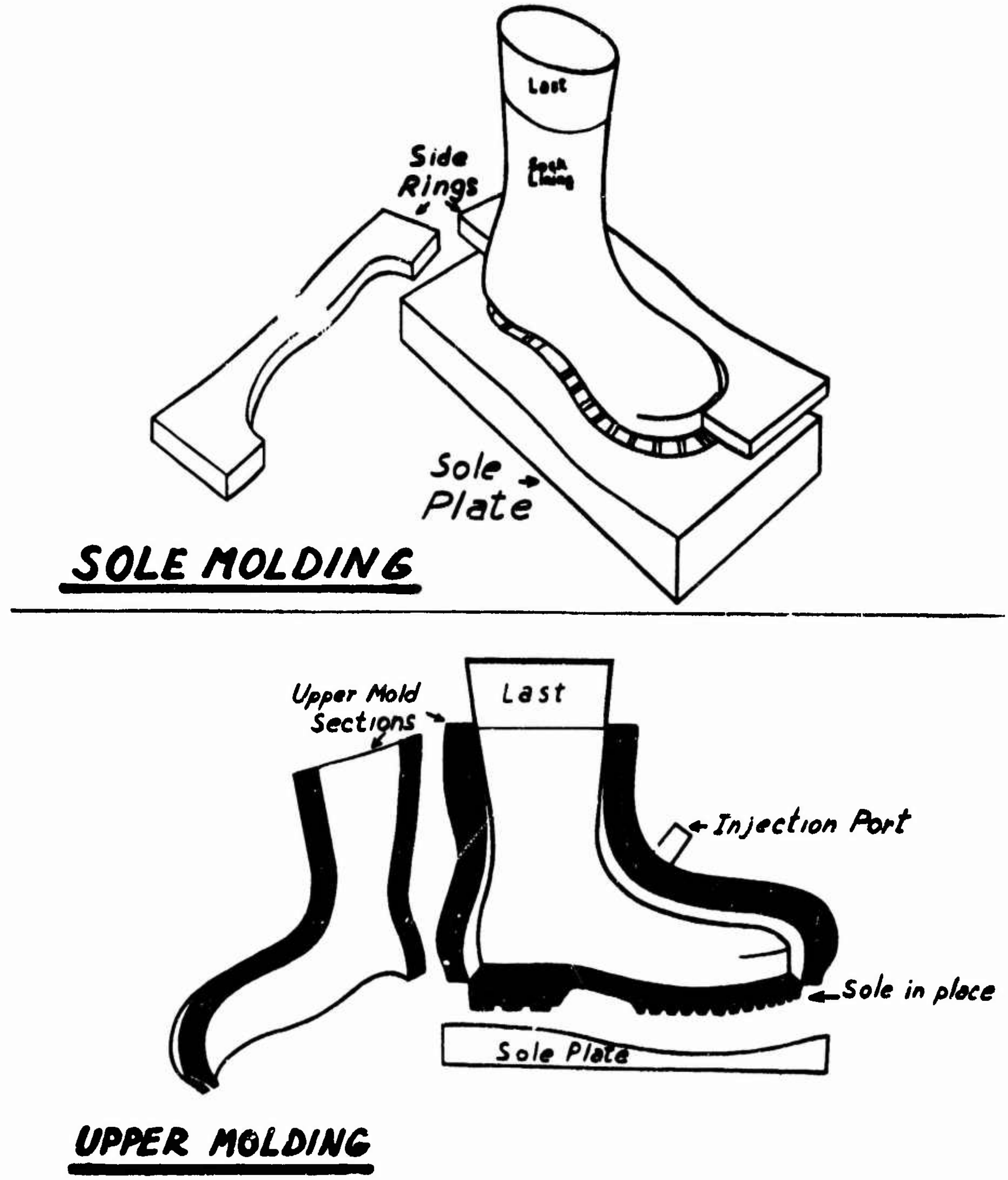


FIGURE 18 - SCHEMATIC OF MOLD SECTIONS

a. Processing Equipment

A Diehl Mateer, three component, polyurethane mixing/metering machine, used to fabricate prototype boots described in this report, was also used to produce the fifty (50) pairs of prototype R-3003. This is laboratory equipment and can be used only for limited production. The three components which are mixed and metered by the machine are (1) prepolymer, (2) curatives and (3) additives which include blowing agent and colorant.

The mold into which the compound is dispensed has been described.

The unit for spraying the skin onto the boot is a two component Binks airless spray gun. The two components used in the gun are prepolymer and curative.

b. Production Cycle

Generally the molding cycle for producing the prototype footwear is as follows:

(1) Preparation of Equipment

(a) Prepolymer tank temperature set at 220°F.
(b) Curing agent tank temperature set at 220°F.
(c) Molds preheated in oven for a minimum of 1 hour at 150°F.

(2) Preparation of Compound

(a) The compound mixtures are prepared and poured into their respective tanks and allowed to warm up for an hour.
(b) The equipment is calibrated to insure output of the proper compound mole ratio.
(c) Sample of compound is checked for expansion properties and rate of cure.

(3) Molding Cycle

(a) Prepare socklining and coat seams* to prevent compound seepage through seam of sock. The nylon socklining is placed on the preheated last and secured to the top of the last to prevent wrinkles during the molding cycle.

* Seam Sealant: Solution of 80% THF and 20% Estane 5707.

(b) The last with the nylon socklining is returned to the oven to re-heat to 150°F and then removed.
(c) The pre-heated (150°F) outsole section of the mold including the side rings is assembled and attached to the preheated socklined last.
(d) The last with socklining is raised and three hundred grams of liquid polyurethane compound are metered into the outsole mold cavity.
(e) Close outsole mold by lowering last into place. (The last to act as mold cover.)
(f) The assembly consisting of the socklined last and the outsole section is placed in an oven set at 250°F for fifteen minutes to expand and partially cure the outsole.
(g) The mold assembly is removed from the oven, and the outside rings are removed from the outsole mold. The preheated upper mold halves are positioned around the outsole and socklined last and attached to the mold assembly.
(h) Two hundred and fifty grams of liquid polyurethane upper compound are metered into the upper section of the mold.
(i) The entire assembly is placed in an oven set at 250°F for thirty minutes to cure upper and outsole together.
(j) The mold is removed from oven, disassembled and the boot stripped from last.
(k) Flash is trimmed from the demolded boot and boot cut to a height of 10½ inches.

(4) Application of Outer Skin

(a) A two component spray solution is prepared.
(b) The boot is placed on a spraying last and four separate spray coats are applied.
(c) After each coat the boot is rotated until the spray sets to prevent dripping and rippling of boot.
(d) The sprayed boot is placed in an oven set at 150°F for one hour to cure spray solution.
(e) The completed boot is refinished by trimming overspray at top of boot and lightly buffing outsole to remove overspray runs that have developed.

(5) A silicone spray IMS,CO #S512) coating is applied to the outer skin of the completed boots for esthetic purposes and to provide a glossy finish.

(6) Boots inspected and packaged.

Fifty (50) pairs of prototype R-3003 boots in size 10R weighing between 23 and 27 ounces per boot were produced by the integrally cast technique. The three component parts (socklining, upper, outsole) required to produce prototype R-3003 prior to the application of the outer spray skin are shown in Figure 19. An actual completed prototype pair is shown in Figure 10. The fifty pairs of footwear produced may be described as follows:

BOOT, LIGHTWEIGHT INSULATED (BLACK) FOR COLD-WET USE

(STYLE R-3003)

The lightweight insulated footwear is a polyurethane integrally cast boot of pull-on style requiring no lacing and is approximately 10.75 inches high. The 0.75 inch thick outsole is produced in a "Lug" tread design from a nitrogen expanded polyether type polyurethane liquid prepolymer resulting in an average density of 28 pounds per cubic foot. The outsole thickness as measured in the toe area from the interior of the boot to the exterior edge of the tread design is 1.0 inches. The outsole thickness as measured in the ball of the foot from the interior to the exterior edge of the tread is 0.875 inches. The depth of the outsole tread is 0.25 inches. The insulating materials as it is expanded in the upper part of the boot is a 12 pound per cubic foot polyurethane (approximately 90% closed cell). The insulation thickness in the toe area is 0.70 inches and tapers off to 0.10 inches at the top of the boot above the ankle. The black inner lining or socklining of the footwear is a nylon rubber-cotton laminate. The natural rubber interface of the socklining is vulcanized prior to stitching. The cotton is tightly adhered to the insulating material with the nylon towards the foot, to help provide slip for donning and doffing. To provide a durable abrasion-resistant exterior the footwear has a sprayed-on black outside solid skin of polyether-type polyurethane (average thickness 0.020 inches). In size 10R the boot weighs approximately 24-27 ounces per boot.

8. Consideration of Commercial Aspects

The molding cycle developed and the equipment used may be considered as designed for producing small quantities of boots in the laboratory. Since no large quantities of boots were produced, no substantial consideration could be given to the development of equipment and procedures for large scale commercial production procedures.

At this time during the development cycle there is no large scale production capability within the industry to produce the lightweight insulated boot commercially in large quantities. However, based upon existing polyurethane equipment and technology, it is believed that it is practical to develop an automated system for large scale production of this type of footwear.

FIGURE 19 - COMPONENT PARTS OF PROTOTYPE R-3003 WITHOUT OUTER SKIN

A conceptual automated production procedure is shown in Figure 20.

Using the schematic diagram in Figure 20, the proposed automated production procedure can take place as follows:

a. The previously prepared socklining is mounted onto the last.
b. The outsole mold is assembled automatically.
c. The liquid polyurethane compound is injected into the outsole mold cavity.
d. The outsole is allowed to expand and semi-cure for five minutes.
e. The rings forming the top edge of the outsole open automatically.
f. The upper mold sections are assembled around the last and top edge of the outsole automatically.
g. The upper insulation liquid polyurethane compound is injected into the upper mold cavity.
h. The upper is allowed to expand and the cast boot is cured for 20 minutes.
i. The mold is disassembled automatically and the boot is automatically stripped from the last.
j. The boot is trimmed to the correct height and the flash is removed.
k. The trimmed boot is mounted onto the spraying last and the combination placed upon the spraying conveyor.
l. Two spray coats are applied automatically to the cast boot by electrostatic airless equipment.
m. The completed boot is dried and finished.

It is recognized that this automated production procedure for producing lightweight insulated boots on a large scale production basis is conceptual and although considered practical has not been reduced to practice. There is currently no available equipment to produce this boot by the procedure presented in Figure 20.

However, there are several major corporations in this country that are currently producing or marketing automated liquid polyurethane injection molding equipment. The existing automated equipment is generally being used to directly mold low gravity expanded polyurethane outsoles from liquid compounds onto all types of footwear uppers. Some of the equipment appears to have the ability to produce a completely expanded boot for civilian use with some insulating characteristics. The multi-station automated equipment currently in existence exhibits anywhere from 12 to 32 molding stations for each complete automated mixing and metering unit.

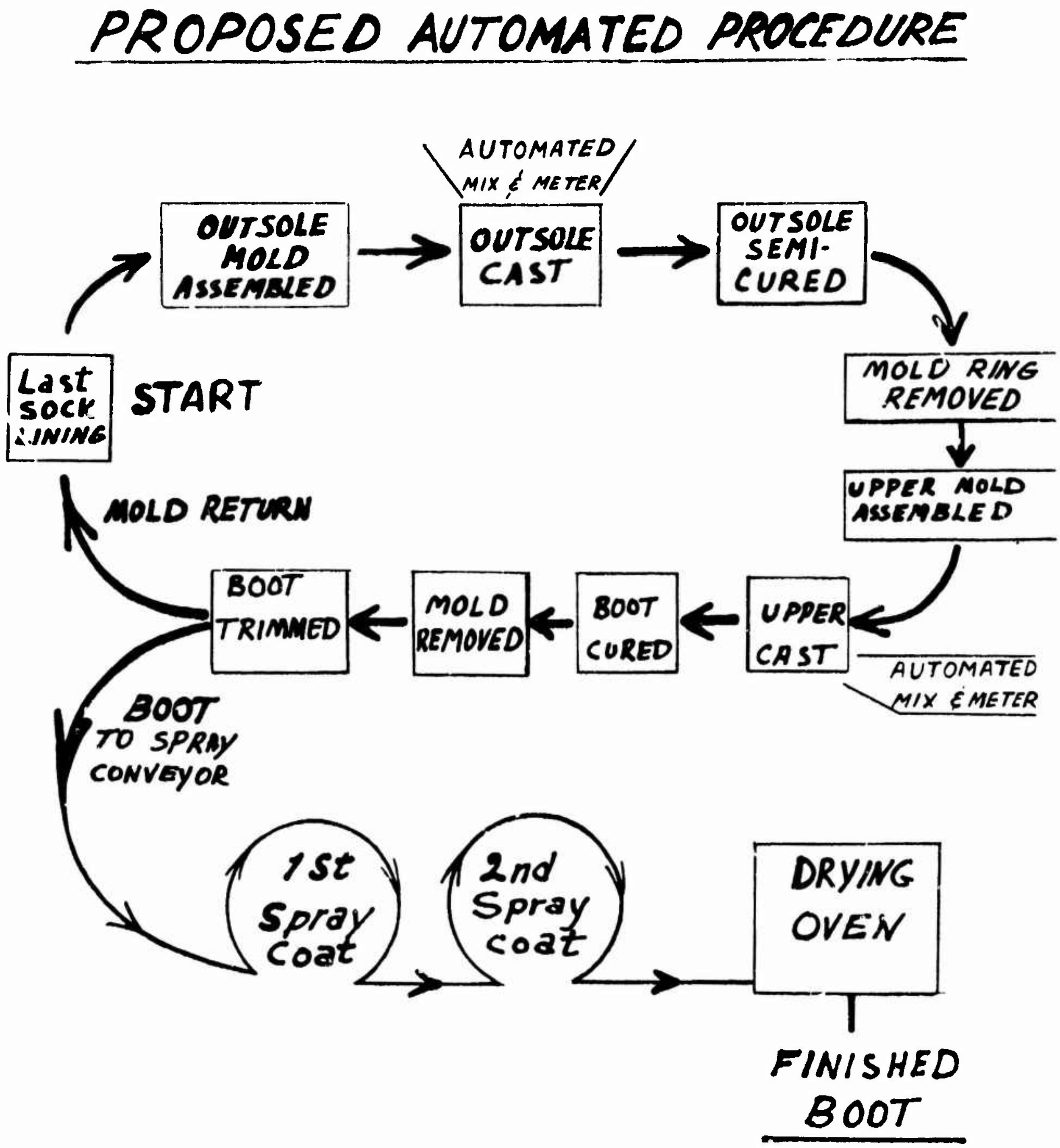


FIGURE 20 - SCHEMATIC OF PROPOSED AUTOMATED PRODUCTION PROCEDURE

Generally, the automated equipment available at this time can be placed into two categories: (1) the one shot system - this system requires that all of the ingredients be accurately metered into the mixing chamber and react together while being mixed to form the required polyurethane system. This technique precludes prereactions. (2) The two or three or more component prepolymer system - these components consist of (a) prepolymer; (b) curing agent; and (c) blowing agent. This system requires prereactions to form the prepolymer (a) prior to reacting with the other two components (b), (c) in the mixing chamber.

The one shot system is a potential low cost operation since the reactions are initiated with the basic raw materials and no previous additional separate steps are required for prereactions. The equipment required is less complex, because starting materials are less viscous and therefore do not require sophisticated pumping systems and equipment to heat flow lines in order to maintain low viscosity of the liquid ingredients. However, precision metering equipment is required in order to react the ingredients, that have been accurately metered, with each other to produce the required mole ratio which results in the final compound.

Generally the physical properties of compounds produced by the one shot system may not be as good as the properties produced from the prepolymer systems, because of the difficulty in accurately controlling the reactions taking place simultaneously in the mold.

Evaluation of Prototype R-3003 Lightweight Insulated Footwear

The experimental R-3003 footwear produced was evaluated in the laboratory for physical and insulative properties and informally under actual field conditions in limited research tests in Alaska.

A. Determination of Insulative Properties

Ten boots from the fifty pairs produced were selected representing the various minimum to maximum finished weights of footwear and subjected to the sectional copper foot calorimeter for determination of clo values. Table X presents the sectional clo values obtained on each boot. As anticipated the insulation values (clo units) obtained on the ten (10) production boots (Table X) were significantly increased over the insulation values of the initial prototype boot R-3003-2 as shown in Table VII. This was accomplished by adjustment of the time-temperature cycles, as outlined in the production procedures, which resulted in a more uniform cell size and density control. The design and materials were the same as used in the original R-3003-2 prototype.

Generally, the automated equipment available at this time can be placed into two categories: (1) the one shot system - this system requires that all of the ingredients be accurately metered into the mixing chamber and react together while being mixed to form the required polyurethane system. This technique precludes prereactions. (2) The two or three or more component prepolymer system - these components consist of (a) prepolymer; (b) curing agent; and (c) blowing agent. This system requires prereactions to form the prepolymer (a) prior to reacting with the other two components (b), (c) in the mixing chamber.

The one shot system is a potential low cost operation since the reactions are initiated with the basic raw materials and no previous additional separate steps are required for prereactions. The equipment required is less complex, because starting materials are less viscous and therefore do not require sophisticated pumping systems and equipment to heat flow lines in order to maintain low viscosity of the liquid ingredients. However, precision metering equipment is required in order to react the ingredients, that have been accurately metered, with each other to produce the required mole ratio which results in the final compound.

Generally the physical properties of compounds produced by the one shot system may not be as good as the properties produced from the prepolymer systems, because of the difficulty in accurately controlling the reactions taking place simultaneously in the mold.

Evaluation of Prototype R-3003 Lightweight Insulated Footwear

The experimental R-3003 footwear produced was evaluated in the laboratory for physical and insulative properties and informally under actual field conditions in limited research tests in Alaska.

A. Determination of Insulative Properties

Ten boots from the fifty pairs produced were selected representing the various minimum to maximum finished weights of footwear and subjected to the sectional copper foot calorimeter for determination of clo values. Table X presents the sectional clo values obtained on each boot. As anticipated the insulation values (clo units) obtained on the ten (10) production boots (Table X) were significantly increased over the insulation values of the initial prototype boot R-3003-2 as shown in Table VII. This was accomplished by adjustment of the time-temperature cycles, as outlined in the production procedures, which resulted in a more uniform cell size and density control. The design and materials were the same as used in the original R-3003-2 prototype.

TABLE X

SECTIONAL COPPER FOOT DATA

.e R-3003 Boot Numbers	4	6	14	20	24	29	32	44	48	50
Overall Clo	2.02	2.10	2.05	1.97	1.94	2.19	2.10	2.12	2.12	2.00
3-15 Ankle Top	1.71	1.65	1.61	1.65	1.67	1.62	1.62	1.80	1.78	1.65
4-16 Achilles	1.54	1.53	1.68	1.55	1.49	1.67	1.67	1.67	1.66	1.53
5-17 Heel	2.21	2.13	2.45	2.09	2.13	2.37	2.37	2.37	2.34	2.27
6-18 Ankle	1.97	2.09	2.08	1.85	1.92	2.12	2.12	2.66	2.08	1.97
7-19 Tongue	1.89	2.07	1.80	1.98	1.88	1.95	1.95	2.02	2.06	1.90
8-20 Instep (Inner)	2.33	2.57	2.36	2.37	2.18	2.47	2.44	2.42	2.45	2.33
9-21 Instep (Outer)	2.66	2.87	2.76	2.46	2.50	2.85	2.85	2.55	2.59	2.44
10-22 Toecap	2.34	2.32	2.10	2.04	2.15	2.25	2.25	2.21	2.29	2.12
11-23 Foresole	1.96	2.30	2.08	2.10	1.87	2.17	2.17	2.20	2.14	2.05
12-24 Sole	2.24	2.67	2.53	2.43	2.18	2.58	2.58	2.40	2.39	2.29
Wt. in oucnes	26.0	26.7	26.7	24.8	24.6	25.3	23.8	23.3	24.8	24.3

Table XI presents the sectional overall clo values of each of the ten boots and compares the insulation properties to the standard cold-dry and cold-wet insulated boots and to the original R-3003-2 prototype. In addition, the overall weights of the boots are presented for comparison purposes.

TABLE XI

SECTIONAL COPPER FOOT DATA

	Overall Clo	Weight - Ozs.
Standard Cold-Dry	1.94	48
Standard Cold-Wet	1.76	44
Prototype R-3003-2	1.84	27
Production Boots		
Number 4	2.02	26
6	2.10	26.7
14	2.05	26.7
20	1.97	24.8
24	1.94	24.6
29	2.19	25.3
32	2.10	23.8
44	2.12	23.3
48	2.12	24.8
50	2.00	24.3
Avg clo	2.061	

A statistical analysis conducted on the ten production boots indicates that on a large production basis 90 percent of the boots should exhibit clo values between 1.905 clo to 2.217 clo.

The insulation data in Table XI indicates that only two (2) of the production prototype boots (numbers 20 and 24) exhibit a clo value below 2.0. However, these two clo values are significantly higher than the clo values obtained on the standard cold-dry boot. It should be recognized that the prototype boots are being developed to be at least equivalent in insulation values to the standard cold-wet boot. The comparison to the insulation values of the standard cold-dry boot is presented for information purposes.

The clo value difference between the lightest weight boot (number 44) at 23.3 ounces to the heaviest weight boots (numbers 6 and 14) each weighing 26.7 ounces is not considered significant. This data indicates that some changes during processing in weight and or density at the same thickness of material can be tolerated without having a significant effect on insulation values.

It is anticipated that as additional technology is developed and the required processing equipment becomes completely automated, which also includes accurate temperature control of compounding ingredients, assembled molds or mold sections and curing ovens, the clo value range of 1.9 to 2.2 may be narrowed, with a possible minimum of 2.0 clo. In addition, the overall weight differences between the boots may be reduced to a tolerance of plus or minus one ounce per boot.

The data in Table XI is of special significance in that it indicates that this lightweight boot concept can combine the functions of both the standard cold-wet and cold-dry boots in one item. However, this would require development of materials with the required low temperature properties and other required physical characteristics. The materials presently used in producing the R-3003 prototype series do not possess the required low-temperature properties for use in the cold-dry range.

B. Climatic Chamber Evaluation

Four pairs of the boots of which the right boot of each pair was subjected to the sectional copper foot calorimeter (right boot numbers 20, 29, 32, and 50) were compared to the standard (white) cold-dry boot on test subjects in the climatic chambers. The comparison data are presented in Appendix C.

The primary test objective was the evaluation of three auxiliary heated gloves during exposure to simulated Arctic conditions. The standard (white) insulated cold-dry boots were used as part of the standard Arctic uniform in order to protect the test subject at -30°F. The prototype (R-3003) footwear which is being developed for the warmer, cold-wet conditions was included to obtain some preliminary acceptance and protection data on human test subjects during cold exposure.

A comparison of the prototype (R-3003) footwear with the standard (white) insulated cold-dry boot during exposure to a -30°F, 5 mph temperature and wind condition for approximately 2 hours and 25 minutes is presented in Appendix C and indicates the following:

(1) Differences in subjective thermal and comfort evaluation across the two boot types were not significant.

(2) The higher instep temperature recorded for the standard (white) insulated cold-dry boot over that of the prototype boot by the end of the last test session corroborates the copper foot data obtained on Prototype R-3003-2 in Table VII. The Table VII data also shows a higher clo value for the sole area of the standard (cold-dry) insulated boot.

(3) The cause of the differences in foot temperature between the two boots may not be due to the difference in cooling but due to the difference in re-warming as a function of exercise. Since the prototype footwear has an open top while the standard insulated boot is a lace-on type, it appears possible that some of the warm air produced by the body during exercise is

being pumped out into the cold atmosphere. The addition of the snow collar as shown in Figure 14 (Prototype R-3007) should increase the rate of re-warming during the exercise period and thereby may become equivalent in heat retention properties to that of the standard (white) insulated boot.

(4) The temperatures recorded in the final test session are still considered relatively high in both cases and both boots will provide adequate comfort and warmth at the reported temperatures.

C. Field Evaluation of Prototype Footwear

Two separate informal research tests were conducted in Alaska. Twelve pairs of prototype footwear which included 3 boots subjected to the sectional copper foot calorimeter (numbers 4, 24, and 44) were furnished to the U. S. Army Arctic Test Center and an additional twelve pairs which also included three boots subjected to the sectional copper foot calorimeter (numbers 14, 6, and 48) were furnished to the U. S. Army, Alaska.

The test objectives were generally limited to the evaluation of insulation properties, comfort and effects of wear by personnel as they conducted normal daily activities. The standard (black) insulated boot for cold-wet use, which the experimental prototype is being developed to replace, is not currently being used in Alaska. Therefore, all comparisons of the experimental prototype footwear were made against the standard white (cold-dry) boot. Early in the test period both U.S. Army Arctic Test Center and U.S. Army Alaska were authorized to modify the boots by the addition of a snow collar to preclude entry of snow into boot and to prevent heat loss. This closure was based upon the snow collar developed and used on prototype R-3007 shown in Figure 14.

(1) U. S. Army Arctic Test Center Evaluation

The results of the limited research test conducted by the U.S. Army Arctic Test Center are presented in Appendix D.

The test was conducted over a 68-day period and generally indicates the following:

The donning and doffing presented no difficulties.
Six of twelve test participants stated that the boot did not, at one time or another, provide adequate traction when walking on melting ice.
There were no difficulties encountered in operating vehicles, aircraft, and equipment. In addition, there were no problems due to bulkiness of the boots during manipulation of brakes or clutch pedals.
There was no report of damage from the spillage of petroleum products (such as gasoline, diesel, solvent, antifreeze, motor oil and grease) onto the boots.

At the completion of the test it was discovered that approximately 50 percent of the boots exhibited a cut, tear or break in the outerskin. The cause of damage in most cases was reported as unknown. Since the damage was not discovered until the completion of the test, the indications are that there was apparently no effect on insulation properties and that the boots remained serviceable. The boots were worn at temperatures as low as -47°F but since they were developed to function only down to -20°F, the lower temperature may have caused the skin on some of the boots to become brittle and crack or break.

The U.S. Army Arctic Test Center did not present any conclusions because of the limited number of test items and the short period of time that the test was conducted, but did express an opinion that the experimental lightweight footwear was not as durable as the standard (white) insulated cold-dry boot.

The major objective of the work was to achieve insulation equivalent to that of the standard (black) insulated cold-wet boot, with optimum durability achievable at the reduced weight. It is assumed that the durability referenced in the report is puncture resistant.. It is anticipated that puncture resistance can be improved in fabrication of future prototypes by design and material modifications.

(2) U. S. Army Alaska Evaluation

The results of the limited research test conducted by U. S. Army Alaska are presented in Appendix E and include the following:

The U.S. Army Alaska furnished boots to both the 75th Infantry Arctic Rangers and the 19th Aviation Battalion.

The 75th Infantry Arctic Rangers subjected the boots to twenty (20) days wear. The boots were used in skiing seven miles, snowshoeing four miles and walking four consecutive miles per person with no difficulties encountered. No slippage at the heel was encountered while walking, skiing or snowshoeing. In addition, the boots were used in eleven paradrops per person without difficulty.

The 75th Infantry Arctic Rangers further indicated that the support to the foot provided by the boot is excellent and that the ease of donning and doffing and the weight of the experimental boot provide a definite advantage over the standard (white) insulated cold-dry boot. At the completion of the test, there was no evidence of boot damage or wear.

The experimental boots worn by elements of the 19th Aviation Battalion stationed at Fort Wainwright, Alaska, were evaluated primarily for compatibility with aircraft flight controls, for example, rudder pedals and brakes.

The 19th Aviation Battalion members reported that the boots are light and comfortable with the exception of some tightness across the instep. Pedal sensitivity required to manipulate aircraft controls was far superior to that of the standard (white) insulated cold-dry boot. The experimental boot presented no problems in walking but was rather stiff when worn in a sitting position manipulating aircraft controls. Overall the experimental boot was rated superior to the standard (white) insulated cold-dry boot in relation to flying activities.

The results of the limited Alaskan field test generally indicated that the insulation properties of the experimental footwear appear to be adequate, the ease of donning and doffing characteristics are a distinct advantage and the test boots offer a significant weight reduction over the standard boot. However, the limited field test was not conducted for a long enough period of time to determine overall durability characteristics.

D. <u>Determination of Physical Properties</u>

In an effort to establish the basis for the preparation of tentative physical requirements, physical testing was required. Destructive testing of finished footwear is required since the physical properties that would be obtained from evaluation of prepared flat samples may not directly relate to the physical properties of a finished boot, because of the variations of thickness in different areas of the footwear and the possibility of some differences in temperature and time relationships that may be encountered during processing.

The physical properties of three boots selected from the fifty pairs of prototype R-3003 produced were determined by actually dissecting the required test specimens from each boot. The selected boots are identified as follows:

One unused boot (number 95) weighing 715 grams.

Two boots used during the Alaskan test (numbers 66 and 21) weighing 765 grams and 697 grams respectively.

The two used boots were selected to determine what effects on the physical properties, if any, had taken place during use. There was no significant wear noted on the outsoles of these two boots.

The proper dissection of the boots to obtain test specimens was considered critical since the varying thickness of the upper insulation caused by the contour of the boot, as well as the difficulty encountered during the separation of the skin and socklining from the foam, made it difficult to prepare satisfactory test specimens. In some cases the skin had to be carefully abraded away from the foam.

Table XII presents the physical properties obtained on the three boots. The results obtained on the upper foam sections of the boots generally indicate that they are comparable, with the density varying between 10 and 12.8 pounds per cubic foot and the compression deflection at 25 percent between 2.5 and 4.0 pounds. The compression set data obtained at room temperature is erratic and at the elevated temperature (158°F) is considered high.

Since there is a density gradient within the outsole, the variations in density through the cross section of the outsole were anticipated. Some of the variations in density from sole to sole obtained on the worn boots in the same cross sectional area may possibly be attributed to the effects of wear.

Satisfactory samples from the sprayed skin of the unused boot for use in low temperature evaluation were unobtainable. Therefore, no low temperature tests were conducted. In addition the tensile data obtained on the outer skin of worn boot number 66 was considered low.

During sample preparation it was noted that on all boots there were some areas of poor adhesion of the outer sprayed skin to the foam. There was also a lack of adhesion of the outer skin to the outside edge of the outsole.

The limited physical tests obtained in Table XII indicate that it may be difficult to set realistic tolerances on physical property requirements until processing and production techniques are further refined to more accurately control time-temperature relationships and to insure complete mixing of ingredients.

The physical tests were conducted in accordance with test methods listed in Appendix F.

Since it was difficult to obtain satisfactory samples from the dissection of finished footwear and in order to get some indication of how closely the physical property data obtained on prepared flat samples may relate to the results obtained from actual boot sections, flat specimens in various thicknesses were prepared. These samples were prepared using the same formulations and processing procedures used to fabricate the fifty pairs of Prototype R-3003 footwear. Flat samples in the following thicknesses were prepared for evaluation.

Upper insulation foam 15/16 inch thick

Upper insulation foam 5/16 inch thick

Outsole foam 11/16 inch thick

Outsole foam 5/16 inch thick

Outsole foam 1/4 inch thick

Solid outer skin (sprayed) .026 inch thick

Solid outer skin (cast) .060 - .080 inch thick

[illegible] OF PRO[illegible] [illegible]-3003 BOOTS

	Worn Boot #21		Worn Boot #66		Unused Boot #95	
	Upper	Outsole	Upper		Upper	
Density, lbs/cu ft	10.0		12.8		11.1	
Heel		29.5		22.8		25.7
Outsole - Full Thickness		23.9		31.3		30.6
- Top Part		28.6		24.2		26.9
- Bottom Part		29.9		29.6		28.4
- Cleat only		47.1		51.4		42.9
25% Comp/Deflection, lbs	3.0	39.	4.0	24	2.5	24.
50% Comp. Set, %						
22 Hrs at R.T.	9.0	20.0	5.9	9.5	18.4	32.0
22 Hrs at 158°F	95.0	70.5	92.6	83.8	98.0	91.2
Water Absorption, %						
Vacuum Test	225	6.3	190.	17.2	285.	10.8
6 inch head	38.7	8.9	52.	6.7	50.8	8.7
Torsional Stiffness	Outsole					
T_2	(-49°C)		(-52°C)			
T_5	(-55°C)		(-58°C)			
T_{10}	(-61°C)		(-62°C)			
T_{100}	(-70°C)		(-69°C)			
Outerskin						
Tensile lbs/sq. in	2635		1010		2615	
Elong., %	590		460		580	
Die C Tear P.P.I.	204		236		209	

The preparation of thick outer skins by the spray method was not considered practical because of the possibility of solvent entrapment and resultant porosity. It was also anticipated that the physical properties obtained on the sprayed skin versus the cast skin may not correlate since they were produced by different processing techniques. However, these test specimens were evaluated and the data is presented in Tables XIII, XIV, and XV. The overall results indicate that it is difficult to obtain consistent physical data with varying thicknesses of foam using the same formulations and processing techniques as noted in the densities obtained in Table XIII and Table XIV and the tensile values obtained in Table XV. Test results in some cases were unobtainable because of sample thickness.

E. Insulation Evaluation of Commercial Insulated Boots

In order to compare the insulation properties of the experimental prototype footwear (R-3003) to that of currently available commercial insulated footwear, four pairs of various types of commercial insulated boots (farm, industrial and/or sportswear) in size 10 were obtained. All of the boots selected were approximately 12 inches high and had a knitted cotton sock-lining. Figure 21 presents a typical commercial insulated boot of the same type evaluated. Table XVI presents the design and dimensional differences as well as weight and insulation relationships obtained on the commercial boots. In Table XVII, the insulation values (clo units) obtained on the commercial boots are shown and compared with both the standard cold-wet insulated boot and the experimental insulated boot (series R-3003 - average of 10). The four size 10 commercial insulated boots fit snugly on the sectional copper foot. It was determined that a standard size inside dimension (last size) of a standard military size 10R insulated boot would compare more properly to size 11 or 12 commercial insulated boot. The snug fit on the sectional copper foot explains the low overall insulation values obtained (especially in the important toe cap section) on the commercial insulated boots.

Two additional commercial insulated boots were obtained, one size 11 and the other size 12, equivalent in all respects except for size to the size 10 (commercial #3) previously evaluated. These two sizes were selected to determine which size boots most properly fit the sectional copper foot and to determine if higher clo values will be obtained over that of the previously evaluated snug fitting size 10, commercial #3, insulated boot.

The size 11 boot was compatible to the copper foot in length, but slightly snug in width. The size 12 was compatible in width to the copper foot, but slightly too long. None of the commercial insulated boots fit as well as the standard military insulated boots or the experimental insulated boots under development.

FIGURE 21 - TYPICAL COMMERCIAL INSULATED BOOT

TABLE XIII

PROPERTIES OF UPPER INSULATION FOAM

	15/16" Slab	5/16" Slab
Density (lbs/cu. ft.)	11.4	14.6
Tensile PSI	---	132.
300% Modulus PSI	---	60.
Elong. (%)	---	550.
Die B Tear PPI	---	13.
25% Comp. Deflection PSI	4.7	9.6
50% Comp. Set (%)		
22 Hrs @ 158°F	89.7	---
22 Hrs @ 70°F	18.7	---
Water Absorption 6 Inch Head		
24 Hrs.	15.7	10.6
48 Hrs.	25.6	18.5
7 Days	59.1	44.4

TABLE XIV

PROPERTIES OF OUTSOLE FOAM

	11/16" slab	5/16" slab	1/4"slab
Density (lbs/cu. ft.)	29.0	33.7	43.3
Tensile PSI	----	----	440.
300% Modulus RSI	----	----	212.
Elong. (%)	----	----	830.
Die B Tear PPI	----	----	52.
Shore A Hardness	30/45	45	55.
Abrasion Index	5.4	5.4	10.8
50% Comp. Set(%)			
22 Hrs @ 158°F	----	----	89.0
22 Hrs @ 70°F	----	----	29.4
Water absorption 6 Inch head			
24 Hours	2.4	2.6	1.9
48 Hours	2.9	3.3	2.3
7 days	4.1	4.6	3.1
25% Comp Deflection PSI	28.5	39.0	83.5

TABLE XV

PROPERTIES OF SOLID SKINS

	Sprayed Skin	Cast Skin
Thickness	.026	.060-.080
Tensile PSI	1950	3390
300% Modulus PSI	640	550
Elong (%)	520	685
Shore A Hardness	65	61
Die B Tear PPI	63	116
Die C Tear PPI	178	215
Torsional Stiffness		
T_2	-38°C	-45°C
T_5	-57°C	-61°C
T_{10}	-62°C	-64°C
T_{100}	-67°C	-78°C

TABLE XVI

DESIGN AND DIMENSIONAL CHARACTERISTICS OF COMMERCIAL INSULATED FOOTWEAR

	Commercial				Military	
Characteristic	Comm. #1	Comm.#2	Comm.#3	Comm. #4	Standard Cold Wet	Prototype Series-R-3003
Weight	1184	1050	967	1219	1250	708
Insulation Thickness	0.16"	0.16"	0.13"	0.16"	-	0.1 to 0.7"
Insulation - Height up Leg	6 3/4"	6 1/2"	6"	5"	6 3/4"	9 1/2"
Size	10F	10F	10	10	10R	10
No. of Eyelets	8	8	3	8	6	6

TABLE XVII

SECTIONAL COPPER FOOT CALORIMETER DATA (CLO UNITS)

	Commercial				Military	
Foot Sections	Comm-#1	Comm.#2	Comm.#3	Comm.#4	Standard Cold-Wet	Prototype Series R-3003
Overall Value	1.37	1.41	1.16	1.23	1.76	2.06
3-15 Ankle Top	1.17	1.13	1.26	1.01	1.27	1.69
4-16 Achilles	1.34	1.36	1.25	1.05	1.54	1.61
5-17 Heel	1.30	1.32	1.09	1.42	1.90	2.29
6-18 Ankle	1.49	1.65	1.16	1.43	2.01	2.04
7-19 Tongue	1.33	1.41	1.19	1.17	1.32	1.96
8-20 Instep(inner)	1.84	1.97	1.55	1.59	2.63	2.39
9-21 Instep(Outer)	1.38	1.56	1.02	1.19	2.36	2.69
10-22 Toecap	1.02	1.04	0.78	0.87	1.70	2.21
11-23 Foresole	1.72	1.66	1.53	1.47	2.47	2.10
12-24 Sole	2.01	2.05	1.63	1.73	2.72	2.43

Table XVIII presents the results of the sectional copper foot evaluation and as anticipated the overall clo values obtained reflect the differences in fit and weight of materials. The effect of sizing on insulation values is reflected in the data obtained in the instep, heel and Achilles. However, when the experimental prototype (R-3003 series) and the standard military insulated boots are compared in weight and insulation values to the best of the currently available commercial boots, they may be considered as being significantly better. Sectional copper foot data was also obtained on the standard five buckle overshoe and three experimental molded lightweight polyvinyl chloride overshoes. All of the overshoes were evaluated in combination with the standard leather combat boot and are presented in Table XIX for comparison to the lightweight insulated prototype R-3003 boot.

The standard leather combat boots in size 10R weighs at least 28 ounces per boot. The standard 5 buckle overshoe weighs approximately 32 ounces per overshoe. Thus the combination required for use on the sectional copper foot calorimeter has a total weight of at least 60 ounces.

The three lightweight molded polyvinyl chloride overshoes have a full bellow opening with a button and loop closure for ease of don and doff and weigh approximately 16 ounces per overshoe. The total weight of the standard leather combat boot and polyvinyl chloride overshoe combination is at least 44 ounces.

Table XIX compares the clo values obtained on the lightweight insulated (prototype R-3003) boot weighing an average of 24 ounces per boot in size 10, to the values obtained on the standard leather combat boot-overshoe combinations.

Although the overshoes were not developed to provide insulation properties, their insulative characteristics in combination with the standard combat leather footwear is at least equivalent to the previously evaluated commercial insulated boot. However, the insulation values obtained on prototype R-3003, lightweight insulated boots are significantly higher than all combinations evaluated.

F. Program Review

A review of the completed materials research studies, processing techniques, prototype fabrication and evaluation, indicated at this time that the polyurethane technology developed had progressed sufficiently to allow the selection of a prototype boot that should meet the established requirements.

TABLE XVIII

SECTIONAL COPPER FOOT CALORIMETER DATA (CLO UNITS)

COMMERCIAL BOOT #3

Foot Sections	Size 10 967 Grams	Size 11 1127 Grams	Size 12 1166 Grams
Overall Value	1.16	1.30	1.44
3-15 Ankle Top	1.26	1.18	1.23
4-16 Achilles	1.25	1.29	1.44
5-17 Heel	1.09	1.53	1.66
6-18 Ankle	1.16	1.40	1.41
7-19 Tongue	1.19	1.06	1.13
8-20 Instep (inner)	1.55	1.67	1.74
9-21 Instep (outer)	1.02	1.82	1.73
10-22 Toecap	0.78	1.18	1.18
11-23 Foresole	1.53	1.84	1.86
12-24 Sole	1.63	2.30	2.29

TABLE [illegible]

Sectional Copper Foot Calorimeter Data (Clo Units)

Foot Sections	Prototype Series R-3003	5- Buckle	Molded Vinyl #1	Molded Vinyl #2	Molded Vinyl #3
		Leather Combat Boot/Overshoe Combinations			
Overall Value	2.06	1.32	1.43	1.37	1.41
3-15 Ankle Top	1.69	1.21	1.36	1.17	1.31
4-16 Achilles	1.61	1.01	1.19	1.07	1.16
5-17 Heel	2.29	1.28	1.46	1.41	1.35
6-18 Ankle	2.04	1.45	1.59	1.49	1.64
7-19 Tongue	1.96	1.45	1.63	1.62	1.63
8-20 Instep (Inner)	2.39	1.71	1.83	1.78	1.86
9-21 Instep (outer)	2.69	1.46	1.46	1.49	1.47
10-22 Toe Cap	2.21	1.01	1.01	1.04	1.03
11-23 Foresole	2.10	1.23	1.23	1.23	1.24
12-24 Sole	2.43	1.76	1.86	2.01	1.86

Completed performance studies (informal Alaskan field tests, copper foot calorimeter studies, cold chamber tests) indicated that the required thermal insulation properties for a lightweight boot had been achieved. Limited wear tests indicate that such features as durability, service life, comfort during prolonged wear, and design aspects may be adequate.

Based upon the results of the overall review, prototype R-3003 shown in Figure 10 was combined with the outsole design in Figure 15 and the snow collar shown in Prototype R-3007 in Figure 14 were used to form the selected production Prototype shown in Figure 22.

Description of Selected Production Prototype Boot, Lightweight, Insulated (Black), Cold-Wet with Snow Collar

The lightweight insulated footwear is a polyurethane integrally cast boot of pull-on style requiring no lacing and is approximately 10.50 inches high. The 0.75 inch thick outsole is produced from a nitrogen expanded polyether type liquid polyurethane resulting in a core density of 25 to 30 pounds per cubic foot. The outsole design developed, provides increased wear surface dimensions in the ball of the foot and dimensional stability to the boot over that of previous designs. The outsole thickness as measured in the ball of the foot from the interior to the exterior edge of the tread is 0.875 inches. The depth of the outsole tread is 0.25 inches. The insulating material as it is expanded in the upper part of the boot is approximately a 10 pound per cubic foot polyether type polyurethane (approximately 90% closed cell). The insulation thickness in the toe area is 0.70 inches and tapers off to 0.10 inches at the top of the boot above the ankle. The black inner lining or socklining of the footwear is a nylon/rubber/cotton laminate. The natural rubber interface of the socklining is vulcanized prior to stitching. The cotton is tightly adhered to the insulating material with the nylon towards the foot. To provide a durable abrasion - resistant exterior the footwear has a sprayed on black outside solid skin of polyether - type polyurethane (average thickness 0.20 inches). A snow collar is provided to preclude snow entering the boot and to possibly reduce heat loss as a result of the open top design.

The snow collar is 3 inches high and is provided with a lace. It is produced from the same material as the socklining except that the cotton fabric is removed to eliminate water pick up by the snow collar. In size 10R the boot weighs approximately 24 to 28 ounces

FIGURE 22 - SELECTED PRODUCTION PROTOTYPE

per boot. The formulations for the outsole, upper foam and outer skin for use in producing the selected prototype are presented in table XX and the sockling material is presented in Table XXI.

TABLE XX

Formulations for Boot Components

	PHR		
Materials	Outsole	Upper Foam	Outer Skin
Vibrathane B-602	100	100	—
Adiprene L-42	—	—	100
mPDA	4	4	3.4
Nitrosan	1.5	5	—
Santicizer S-140	18	25	—
SF 1079 Silicone Surfactant	1	1	—
SF 69 Silicone Surfactant	—	—	1.3
3041 Black	0.5	1.5	4.3
THF	—	—	106.5
Cyclohexanone	—	—	100.0
Toluene	—	—	86.5

TABLE XXI

SOCKLINING MATERIAL

Nylon	1826 Nylon Tricot Net (2.7 oz/sq yd)
Gum	Natural rubber .006 inch thick
Cotton	300 Cotton Net (3.6 oz/sq yd)

The development of sophisticated equipment and new techniques and processes for handling specialized castable polyurethane systems has progressed to the point where it is considered feasible to produce lightweight insulated footwear on a full production basis.

The significance of this development becomes evident when Figures 23 and 24 are compared. Figure 24 presents the component parts that comprise the selected lightweight insulated prototype (24 to 28 ounces per boot size 10) produced by the integrally cast technique.

FIGURE 23 - COMPONENT PARTS FOR STANDARD BLACK INSULATED BOOT

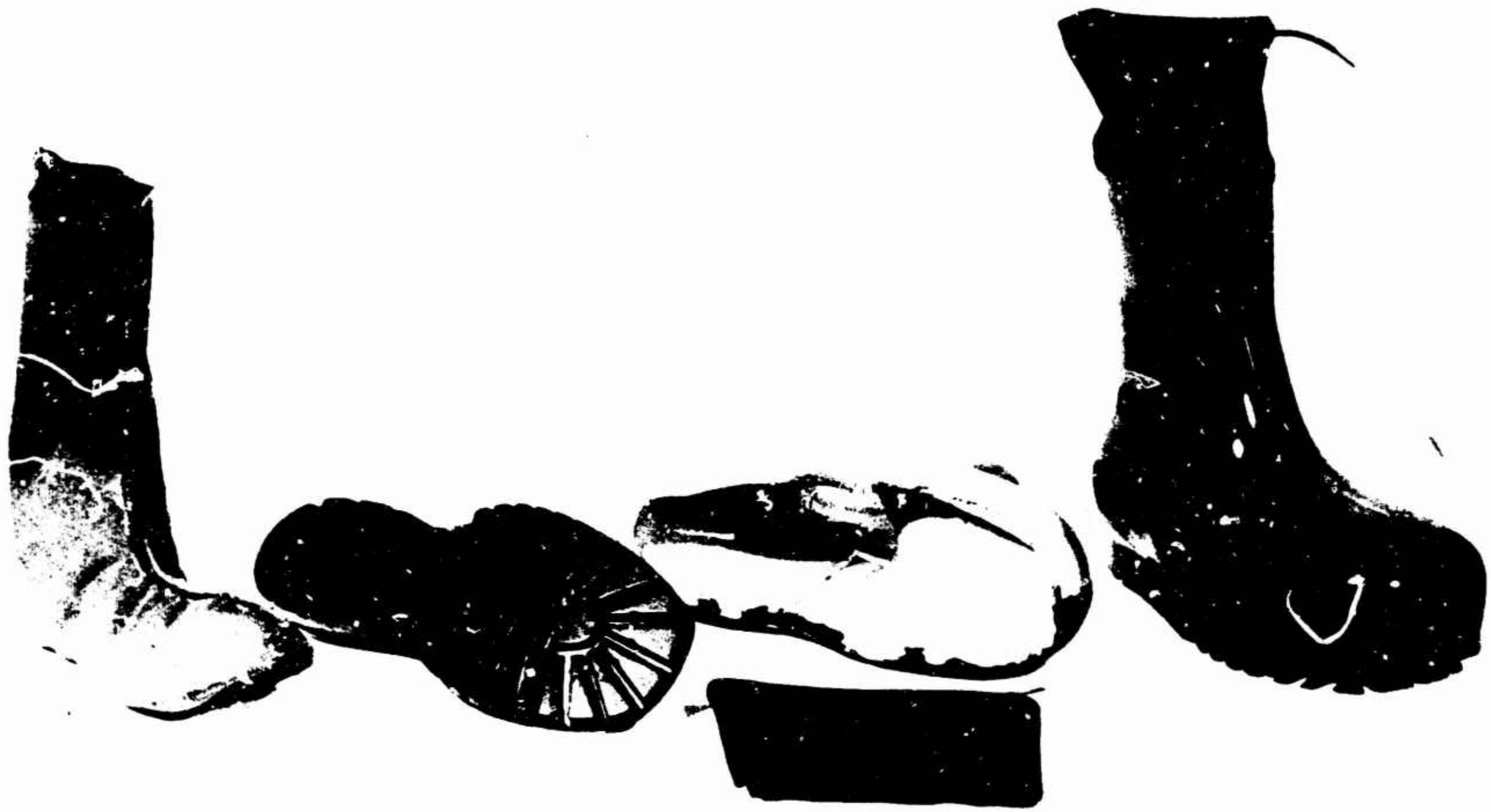


FIGURE 24 - COMPONENT PARTS FOR THE SELECTED PRODUCTION PROTOTYPE

When the four components without the outer spray skin presented in Figure 24 are compared to the 42 different component parts of the conventionally fabricated standard black insulated boot (approximately 44 ounces per boot in size 10) presented in Figure 23, the reduction in the number of components and in the finished weight of the boots becomes obvious. In addition, the reduction to practice of the concept of producing boots in a pull-on type construction by the integrally cast method results in boots that are more reliable from the standpoint of retaining insulating properties, less complex to produce, lighter in weight and lower in cost.

G. Development of Tentative Physical Requirements

Based upon a review of all the physical properties obtained and with consideration given to developed processing procedures, tentative physical requirements were prepared and footwear thickness measurements were determined for use as guidelines during initial production of a limited quantity of footwear for extensive testing. Tables XXII and XXIII present the developed tentative physical requirements.

Prior to initiation of the destructive testing outlined in Tables XXII and XXIII the following tests shall be conducted:

(a) Water Pick-Up - Entire boot immersed for sixteen (16) hours at room temperature - not more than 5.0% increase in weight.

(b) Split boot into two (2) parts along mold-line and obtain boot dimensions and thicknesses.

(c) Measurements for size determination:

1. Upper - After the boot is cut into two (2) parts along the mold lines, refit the sections around the last to insure that the cut edges meet each other and that the proper size dimensions have been achieved.

2. Outsole - Cut out the outsole from the boot and use the last bottom pattern as a measurement device to insure that the proper size dimensions have been achieved. The maximum tolerance shall not exceed +8% at any point on the upper section and outsole. A description of the points at which the thickness measurements are to be made is as follows:

Upper Section

Measurement points 1, 2, 3, 4, 5 and 6 are all located at the top edge of

TABLE XXII

PHYSICAL PROPERTY REQUIREMENTS

Physical Property	Test Method	Outsole	Upper Foam	Outerskin
Color	--	Black	Natural	Black
Core Density lb/ft^3	ASTM D2406-65T Pars 62 thru 67	Min 25.0 Max 30.0	Min 10.0 Max 15.0	-- --
Tensile Strength (PSI)	ASTM D-412-66	--	--	2700 Min
Ultimate Elongation %	ASTM D-412-66	--	--	500 Min
Compression Deflection @ 25% at Room Temp (PSI)	ASTM D1056-67T Pars 17 thru 20	35 Max	6 Max	--
at -20°F (PSI)[1]		Increase not more than 30% from original	Increase not more than 50% from original	--
Compression set at 50% deflection at Room Temp, %	ASTM D1056-67 Pars 21,22 and 23	15 Max	10 Max	--
at 158°F		60 Max	70 Max	--
Cutgrowth 50,000 flexes Original %	ASTM D1052-55	200%	--	--
After aging 70 hours 212°F%	ASTM D573-67T	200%	--	--
Torsional Stiffness	ASTM D-1053-65 (except pars 8 & 9)	-65°F	--	-65°F

PHYSICAL PROPERTY REQUIREMENTS (TABLE II Cont'd)

Physical Property	Test Method	Outsole	Upper Foam	Outerskin
Water Absorption % by weight[2] 6 inch head 48 hours	Fed Std 601 Method 1241	8 Max	50 Max	--
Tear Resistence Die C (PPI)	ASTM D624-54	--	--	250
Hardness Shore A		Min: 45	--	--
Original (Measured on cleats)	ASTMD2240-64T	Max: 65	--	--
After aging 70 hours at 212°F	ASTM D573-67T	Not more than 10 pt change from original	--	--
Hardness Change at -20°F[3]		Not more than 15 pt change from original	--	--

NOTE (1) The test specimen and test apparatus shall be conditioned at -20°F ± 2 for two hours prior to initiating test.

NOTE (2) The complete skin and socklining shall be removed prior to testing.

NOTE (3) A specimen at least 0.250 inches thick and at least 1 inch wide by 2 inches long shall be tested for hardness as specified in ASTM D2240-64T. The same specimen and durometer shall then be conditioned for 2 hours at -20°F (± 3.6°F) and the hardness then determined at that temperature. The difference between the two determinations shall be recorded as the hardness changes.

the boot. Points 1 and 2 are located on each side of the front mold parting line. Points 3 and 4 are located on each side of the rear mold parting line. Points 5 and 6 are located on each side midway between the front and rear mold parting line.

Measurement points 7,8,9,10,11, and 12 are exactly in the same position relative to the mold parting lines as those in the paragraph above except that they are located on a line parallel to the top edge of the boot and 6 inches down from the top edge of the boot.

Measurement points number 13 and 14 are located on each side of the rear mold parting line approximately nine inches down from the top edge of the boot.

Measurement points number 15 and 16 are located 7 inches from the bottom of the outsole measured as a girthing measurement from the toe along the front and to each side of the mold parting line.

Measurement points 17 and 18 are approximately 4½ inches on each side of points 15 and 16 on a line from the mold parting line to the outsole.

Measurement points 19 and 20 are located 3 inches from the bottom of the outsole measured from toe on each side of the front mold parting line.

Measurement points 21 and 22 are located 3 inches on each side of points 19 and 20, on a line from the mold parting line to the outsole.

TABLE XXIII

SOCKLINING PHYSICAL PROPERTY REQUIREMENTS

Physical Property	Federal Test Method Standard No. 191	Socklining
Adhesion lbs/2 inch (Wales direction)	Method 5950	2.0 Min
Tear grams (Wales direction)	Method 5132	2400 Min

MEASUREMENT POINT THICKNESSES

Point Number	Insulation Thickness Range - Inches
1,2,3,4,5,6	.100 - .200
7,8,9,10	.500 - .700
11, 12*	.400 - .600
13, 14	.500 - .700
15, 16	.600 - .800
17, 18	.600 - .800
19, 20	.700 - .900
21, 22	.700 - .900

*Points 11 and 12 are located down from points 5 and 6.

Outsole

Cut the outsole into two parts in the length direction along the center line of the outsole. The following measurements are to be made one inch in from each side of the center line:

Heel 1.750 - 1.850 inches thick includes cleat
Ball 1.000 - 1.100 inches thick includes cleat
Arch .750 - .850 inches thick includes no cleat
Cleat .200 - .300 inches thick

Since existing laboratory solid rubber abrasion tests are not capable of properly evaluating abrasion characteristics of cellular materials no abrasion test was specified. Limited wear tests will be used in an attempt to establish a relationship between physical

properties and actual wear characteristics.

It is recognized that these tentative physical properties are based upon limited data and the fabrication of small quantities of experimental boots. These tentative requirements will be used as guidelines until large enough quantities of boots have been fabricated in a pilot plant or semi-works production facility using closely controlled processing techniques and semi-automated production procedures. The fabrication of large quantities of boots will permit more extensive physical testing and evaluation of all aspects of the produced footwear resulting in the achievement of optimum performance requirements.

H. Production of Footwear

The developed laboratory procedures have been used to design a semi-works production facility in which the metering and mixing of materials is automatic, and the spraying of the molded boot is automated. The development and installation of this semi-works facility provide the elements for the final step which would be the installation of a commercial plant for full scale production of lightweight insulated footwear. The semi-works facility based upon the initial production of experimental lightweight insulated footwear in sizes 8, 9, and 10 indicates that the economics and the process evolved may be satisfactory for the final commercialization of this new concept of lightweight insulated footwear, which may become a standard item for military use.

It is recognized that during the continual evolution of the item to its optimum development and efficiency there may be some changes and modifications made to materials, design and processes. However, the feasibility of the concept and production of this new footwear has been determined to be practical and economically feasible.

The established production techniques indicate that the process developed and the types of formulations being used allow the required flexibility to make desired changes in physical properties and or design.

The development of the lightweight insulated footwear including laboratory evaluation and consideration of commercial producibility has been completed to the point that extended durability tests under field conditions are necessary to confirm laboratory data, develop use concepts and establish final performance requirements.

11. Conclusions

The data and techniques developed under this program demonstrated the feasibility of meeting the original goals. The resultant boots are lightweight, impermeable and provide protection for 2 hours inactivity at -20°F. The average weight of a size 10 boot is 24 to 28 ounces (approximately 20 ounces less than the standard cold-wet boot) and the water absorption is less than 5% by weight. In addition, the integrally cast technique developed significantly reduces the number of parts required, eliminates seams, and the need for adhesives and complex fabrication techniques that could result in weak areas and possible points of failure in boots assembled by conventional methods.

Insulative properties are equal to or better than the standard (black) insulated boot for cold-wet use and show no significant change in insulation after wear. The results of the initial production of lightweight insulated footwear indicate that the economics and processes evolved may be satisfactory for the final commercialization of this new concept of lightweight insulated footwear. The fabrication procedures within the semi-works production facility are basically manual with the exception of the metering and mixing equipment and the automated electrostatic spray process for the application of the outer skin.

Based upon the satisfactory completion of the Alaskan research test, to be conducted by the U. S. Army Test and Evaluation Command during the winter of 1973-74, it is planned to obtain necessary funds to assist industry in establishing a completely automated large-scale production capability to mass produce the newly-developed cold-weather insulated boot.

12. Summary

The boots developed under this program may be considered the first generation in a new concept of lightweight insulated military footwear. The results of materials research studies, design development, and the establishment of processing techniques demonstrated that lightweight insulated footwear may be produced by integrally casting and expanding liquid polyurethane systems.

Completed performance studies and sectional copper foot calorimeter data indicate that the required thermal insulation properties have been achieved.

Maximum weight reduction of insulated footwear produced in a pull-on type construction, while retaining other required properties, was achieved by the use of the integrally cast technique.

A reduction to practice of the concept of integrally cast expanded polyurethane footwear was achieved.

Tentative physical property requirements were prepared.

Production procedures were established, and a semi-works production factility was designed and put into operation.

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3. Pooley, R.W., andA.D.Shaw, and C.S. Rohs, Lightweight Insulated Footwear. Uniroyal, Incorporated, Contract No. DA19-129-AMC-959 (N), U.S. Army Natick Laboratories TR69-16-CM, July 1968.

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6. Mazzeo, R.A. Lightweight Insulated Footwear Uniroyal Inc., Contract No. DAAG17-70-C-0003 TR72-9-CE (C&PLSEL-89) Sept. 71.

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APPENDIX A

FORMULATIONS AND PHYSICAL PROPERTIES OF BOOT COMPONENTS

COMPOSITION (PHR)	OUTSOLE	UPPER	OUTER SKIN
Vibrathane B-602	100	100	-
Vibrathane B-605	-	-	100
Santicizer S-140	25	25	40
MPDA	4	4	3.8
Santicizer S-160	4	4	-
SF-1079 Silicone	2	2	-
Nitrosan	0.7	7	-
US-15N	0.7	3	-
3041 Black	2.1	-	5
Toluene	-	-	200
THF	-	-	51.2

PHYSICAL PROPERTIES			
100% Modulus (PSI)	33	12	360
300% Modulus (PSI)	138	47	800
Elongation (%)	550	440	570
Tensile Strength (PSI)	290	65	2840
Split Tear (PPI)	5	2	22
Die C Tear (PPI)	-	-	320
Density (lbs/cu. ft)	28	12	-
25% Compression Deflection			
@70° F(PSI)	33.8	5.5	-
@-20°F(PSI)	45.0	13	-
50% compression Set			
After 22 Hrs @158°F	25	68	-
After 22 Hrs @70°F	8	0	-
25% Compression Set			
After 22 Hrs @-20°F			
Reading after 10 sec.	100	96.4	-
Reading after 30 min.	92.5	94.2	-
NBS abrasion	22	-	-
Torsional Stiffness			
T_2	-	-	+9°F
T_5	-	-	-39°F
T_{10}	-	-	-67°F
T_{100}	-	-	-100°F

APPENDIX B

BOOT # IC-312 - Chemical and Physical Property Description

Integrally Cast, No Shank
Prototype A, Modification 1

Sock Weight	17 grams
Outsole Weight	310 grams
Upper Insulation Weight	153 grams
Skin Weight	36 grams
Overall Weight	18.2 oz.

Insulation Thickness - Mils

Upper	Side	Front	Back
Top	70	180	180
Ankle	180	450	300
Heel	-	-	370
Instep	360	500	-
Toe	500	500	

Outsole	
Heel	1200
Arch	550
Ball	780

Compounds Used:	PHR
Socklining - Solid	
Skin	
Roylar A 850	100
Outsole	
Vibrathane B-602	100
1570 Black	.3
SF-1079 Silicone	2.0
Methylene Chloride	11.0
M-Phenylenediamine	4.0
Santicizer S-160	4.0
Upper Insulation	
Vibrathane B-602	100
1570 Black	.3
SF-1079 Silicone	2.0
Nitrosan Dispersion	10.0
MOCA	9.0

APPENDIX B (Cont'd)

BOOT #IC-312 Chemical and Physical Property Description

Outer SKin

Vibrathane B-602	100
Nitrocellulose Black	2
M-Phenylenediamine	4

Physical Properties

Sock Lining

Tensile Modulus @ 100%	1200 psi
Tensile	6500 psi
Elongation	550%
Tear, Die C	700 ppi
Tear, Split	400 ppi

Outsole

Density	28 pcf
Compressibility	45 psi
Compression Set	20%
NBS Abrasion	225
Water Absorption	1.2%

Upper Insulation

Density	8 pcf
Compressibility	3 psi
Compression Set	25%

Skin

Tensile Modulus 100%	500 psi
Tensile	7200 psi
Elongation	530%
Tear Did C	470 ppi
Tear, Split	80 ppi

APPENDIX C

REPORT OF CLIMATIC CHAMBER TESTS OF ARTIC BOOTS

by John M. Lockhart

Chamber Conditions: Subjects were exposed to a -30°F. temperature and 5 mph wind condition for approximately 2 hours and 25 minutes.

Number of Subjects: 51 subjects were exposed to the chamber condition. 20 subjects wore the Standard White Artic boot and 31 subjects wore the Prototype Black boot. Since subjects were removed from the chamber when their hand skin temperature reached or dropped below 39°F, data analysis was completed using only those subjects who were exposed for the entire session. Of these subjects, 15 subjects wore the Standard White Arctic boot and 22 subjects wore the Prototype Black boot.

Activity of Subjects: Immediately upon entering the test chamber, all subjects performed manual tasks while standing at a table for approximately 25 minutes. After this test period, the subjects walked on a treadmill at the rate of about 2.5 mph for 35 minutes. After the first treadmill period, the subjects performed for a second test period, then a second treadmill period and finally a third test period before leaving the chamber.

Measures: Surface temperatures were recorded throughout the exposure condition from the big toe of both feet and from the instep of the left foot. The thermocouples on the big toes were placed just below the base of both nails. After leaving the chambers, but before undressing, all subjects filled out a questionnaire concerning foot comfort and thermal sensation.

Results: The questionnaire responses for all test subjects who completed the exposure condition are presented in Table 1. The numbers in Table 1 represent the number of subjects who assigned that particular rating to the boots they were wearing. Responses to question 3 were not analyzed. Analyses of variance of responses to questions 1 and 2 showed no significant differences between boots. However, the trend was for the Standard boot to be rated as more comfortable and warmer than the Prototype boot.

Table 1. Questionnaire Data

	Boot Type	
	Standard	Prototype
1. Under these environmental conditions, my feet were:		
a. very comfortable	9	5
b. comfortable	3	8
c. fairly comfortable	2	6
d. neither comfortable nor uncomfortable	0	0
e. somewhat uncomfortable	0	2
f. uncomfortable	1	1
g. very uncomfortable	0	0
2. My feet were:		
a. very cold	0	0
b. cold	1	3
c. cool	1	3
d. about the right temperature	6	12
e. warm	7	4
f. hot	0	0
g. very hot	0	0
3. The amount of frost forming inside either boot was:		
a. none	13	18
b. a little	1	3
c. some	0	0
d. a lot	1	0

The skin temperature data used were those readings obtained from the right big toe, left big toe, and left instep of the subjects. The test periods during which subjects performed manual tasks were analyzed separately from those periods during which they walked on the treadmill. One temperature reading was obtained for each subject at the beginning of each of these periods and another at the end. The number of complete temperature records obtained from subjects wearing the Standard boots and those wearing the Prototype boots differed for each analysis. The loss of some temperature data was due to broken thermocouples. The overall mean surface temperatures for each boot type for each analysis and the number of subjects in each analysis are presented in Table 2. The effect of boot type on skin temperature was significant only in the analysis of the instep surface temperature for both the test and treadmill sessions. A higher instep temperature was found for the Standard boot than for the Prototype boot.

Table 2. Overall Mean Surface Foot Temperature for Two Boot Types During Exposure to -30°F., 5 mph Wind Condition.

Recording Site	Number of Subjects	Treadmill		Activity Session Number of Subjects	Test	
Right Big Toe						
Standard	11	82.4	(NS)	10	81.3	(NS)
Prototype	12	79.3		13	78.6	
Left Big Toe						
Standard	9	77.7	(NS)	8	77.6	(NS)
Prototype	17	78.6		16	80.0	
Left Instep						
Standard	12	86.7	(p.01)	11	86.8	(p.025)
Prototype	19	81.6		19	83.0	

Note: p. indicates probability level for significant main effect. NS indicates a nonsignificant main effect.

Surface temperature at all three points dropped significantly across the three test sessions and across the two treadmill sessions. During the test session surface temperature at all three recording sites dropped significantly by the end of the session. During the treadmill sessions, surface temperature at all three recording sites had risen significantly by the end of the session. Five of six interactions between boot type and with treadmill sessions or test sessions were significant. The mean surface temperatures for both boot types across each activity session are presented in Table 3. In general, surface temperature at all three recording sites for the Prototype boot was not lower than the surface temperature for the Standard boot during the first test session and the first treadmill session. By the end of the last test session, the right big toe and left instep surface temperatures were lower for the Prototype boot than for the Standard boot. Since the treadmill sessions served to rewarm the foot temperature at all three recording sites, it is assumed that the final difference found between boot type was not due to differences in cooling but due to differences in rewarming as a function of exercise. In a conversation between the author and the developer of the Prototype boot, the developer mentioned a modification involving the addition of a snow collar to be attached to the top of the boot so that the boot may be tightened around the leg. It is proposed that this modification would increase the rewarming capability of the boot during exercise resulting in foot surface temperatures very similar to those for the Standard White Arctic boot.

Table 3. Mean Surface Temperature for Two Boot Types during -30°F., 5 mph Wind Exposure Condition

Surface Temperature Recording Sites	Test 1	Treadmill 1	Test 2	Treadmill 2	Test 3
Right Big Toe					
Standard	84.4		80.8		78.8 (p.025)
Prototype	87.0		79.6		69.3
Standard		84.0		80.8 (p.025)	
Prototype		84.1		74.5	
Left Big Toe					
Standard	82.4		76.3		73.8 (NS)
Prototype	87.0		80.8		72.0
Standard		80.3		75.1 (p.05)	
Prototype		84.1		73.2	

Recording Sites	Test 1	Treadmill 1	Test 2	Treadmill 2	Test 3
Left Instep					
Standard	88.0		87.0		85.4 (p.005)
Prototype	87.2		82.8		78.8
Standard		87.2		86.2 (p.001)	
Prototype		84.3		78.8	

Note: p. Indicates probability level for significant interaction. NS indicates a nonsignificant interaction.

Summary and Conclusion: A Prototype Black Cold Weather boot was compared with the Standard White Arctic boot during exposure to a -30°F., 5 mph wind condition for approximately 2 hours and 25 minutes. Differences in subjective thermal and comfort evaluations across the two boot types were not significant. Foot surface temperature was significantly lower for the Prototype boot than for the Standard boot by the end of the exposure period. It is recommended that further chamber tests be done under more extreme temperature and windspeed conditions for longer periods of time using a recent modification of the Prototype boot.

APPENDIX D

Letter Report of Customer Test of the Boot, Insulated, Lightweight
by
United States Army Arctic Test Center

DEPARTMENT OF THE ARMY
UNITED STATES ARMY ARCTIC TEST CENTER
APO SEATTLE 98733

STEAC-MT-ENI

5 May 1971

SUBJECT: Letter Report of Customer Test of the Boot, Insulated, Lightweight, USATECOM Project No. 8-EI-485-000-02X3

Commanding General
U. S. Army Natick Laboratories
ATTN: AMXRE-CE
Natick, Massachusetts 01760

1. References:

a. Letter, AMXRE-CE, Natick Laboratories, 12 January 1971, subject: Request for Engineering Design Test Boot, Insulated, Lightweight.

b. Letter, AMSTE-BC, USATECOM, 21 January 1971, subject: Customer Test/Support Directive: Engineering Design Test of Boot, Insulated, Lightweight.

c. Final Report, Research Test of Lightweight Insulated Boot Under Arctic Winter Conditions, USATECOM Project No. 8-7-6007-01, dated 31 May 1968.

2. Background:

a. Materials Research conducted by NLABS resulted in the development of a lightweight material with high insulative properties. In order to assess this material and gain experience in its use, a Research Test (reference 1c) was conducted at USAATC on prototype footwear fabricated with the new material.

b. As a result of the experienced gained in the Research Test and additional laboratory studies, NLABS has developed a second prototype, lightweight, insulated boot designed for use in the same climatic range as the current Standard Boot, Insulated, Cold Weather, Man's, Rubber, Black.

c. It was requested that a limited Engineering Design Test be conducted on 12 pairs of these experimental lightweight insulated boots.

3. Test Objective:

The objective of this test was limited to the evaluation of the effects of wear by Arctic Test Center personnel as they conducted normal outdoor testing activities.

4. Method:

a. Twelve pairs of boots, all size 10R, arrived at the Arctic Test Center 8 February 1971 from Natick Laboratories. The boots were visually inspected for any defects and were weighed and measured.

b. The boots were issued to 12 personnel involved in testing and duty soldier activities in an arctic environment. These participants stated that the fit of the boot felt normal and volunteered to test the boot. Their foot sizes ranged from 8EEE to 11 1/2E as measured with the Foot Measuring Device, Mens', Both Feet Simultaneously, FSN: 8335-267-2965.

c. The test was conducted over a 68-day period. Each day the boots were worn, a questionnaire was completed (inclosure 1). Testing was conducted in temperatures ranging from -47°F to above freezing (inclosure 2) in terrain and weather typical of that encountered in an arctic environment.

d. In an effort to reduce heat loss and preclude snow entering the boot as a result of the open top design, a modification was suggested and approved by Dr. Malcom Henry of Natick Laboratories. The modification was applied at this Center and consisted of a folded piece of 7.25-ounce water repellent nylon duck 5.5 inches high sewed to the boot upper with a drawstring to snug the boot down around the calf of the leg.

e. During early April, the temperature at the Arctic Test Center rose to above freezing and permission was requested and received from

Mr. Tom Dee of the Infantry Directorate at USATECOM to terminate the test as of 16 April 1971. The detailed results of test and the test boots are being forwarded to Natick Laboratories by separate correspondence.

5. Summary of Results:

a. Results of the Preoperational Inspection:

	Left	Right
Average height from heel to top of boot	10.79 in.	10.76 in.
Average length from toe to heel	12.16 in.	12.15 in.
Average width of boot at widest point	4.93 in.	4.89 in.
Average tread depth of sole	0.201 in.	0.265 in.
Average tread depth of heel	0.257 in.	0.270 in.
Average weight of boot	1 lb. 8 oz.	1 lb. 7.5 oz.

b. Effects of Wear by USAATC Personnel:

(1) Donning and Doffing. Eleven of the twelve test participants stated that donning and doffing presented no difficulties. Difficulties were reported by one individual whose feet measured 11 1/2E.

(2) Traction. Six of the twelve test participants stated that the boot did not, at one time or another, provide adequate traction when walking on melting ice.

(3) Boot Damage Discovered at the Completion of Testing (the term "cut" is used to indicate a long cut, tear, or crack in the boot).

Boot No.	Left	Right
T1	No damage.	No damage.
T2	Two-inch cut across top of toe approximately 1/8-inch deep. Cause: Unknown. One-inch cut along left side approximately 1/4-inch deep. Cause: Snagged on an object while walking.	One-half inch puncture on right side, approximately 1/4-inch deep. Cause: Recovering from hole covered with snow approximately 3 feet deep.

Boot No.	Left	Right
	Two-inch cut along left side of heel approximately 1/8-inch deep. Cause: Unknown.	
	One-inch cut on the heel approximately 1/8-inch deep. Cause: Unknown.	
T3	One-fourth-inch cut on heel approximately 1/8-inch deep. Cause: Unknown.	One-fourth-inch puncture on toe approximately 1/4-inch deep. Cause: Unknown.
		One-inch cut on heel approximately 1/4-inch deep. Cause: Unknown.
T4	No damage.	One-half-inch puncture on left side approximately 1/4-inch deep. Cause: Unknown.
T5	No damage.	No damage.
T6	One and one-half-inch cut on heel approximately 1/8-inch deep. Cause: Unknown.	One-half-inch cut on heel approximately 1/8-inch deep. Cause: Unknown.
T7	No damage.	No damage.
T8	Several lugs on center sole missing. Possible cause: extensive vehicle operation.	One-fourth-inch puncture on left side approximately 1/8-inch deep. Cause: Unknown.
		Several lugs missing on center sole. Possible cause: Extensive vehicle operation.

Boot No.	Left	Right
T9	One-half-inch puncture on left side approximately 1/8-inch deep. One-half-inch puncture on toe approximately 1/4-inch deep. One-fourth inch cut on heel approximately 1/8-inch deep. One-fourth-inch cut on left side of heel. Causes: Unknown.	Two-inch cut on heel approximately 1/8-inch deep. Cause: Unknown.
T10	No damage.	No damage.
T11	No damage.	No damage.

(4) Effect of Petroleum Products (Gasoline, Diesel, Solvent, Antifreeze, Motor Oil, and Grease). Six test participants reported instances of petroleum product spillage on the boots. No damage resulted.

(5) Difficulties in Operating Vehicles, Aircraft, and Equipment. No problems due to bulkiness, manipulation of clutch pedals, brakes, etc., were reported.

(6) Compatibility with Military Skis and Snowshoes:

(a) One test participant, foot size 10D, experienced in snowshoeing, wore the boots while fitted with the U. S. Army Wooden "Trail" snowshoe and reported no difficulty.

(b) One proficient skier, foot size 11EE, fitted with the current Standard A cross-country ski, reported that the test boot offers less ankle support than the White Vapor Barrier boot or the Mountain and Ski boot. It was also reported that excessive heel lift occurred when lunging forward as in a "one step" ski movement.

(7) Insulative Value:

(a) Two test participants reported instances where their feet got cold. All instances reported were prior to the addition of the gauntlet to the boot.

(b) The circumstances were as follows:

Participant Number 1

Foot Size	Ambient Temperature	Exposure	Activity
11 1/2E	-15°F to -30°F	2 hours	Vehicle test officer (supervisory)
	-25°F	4 hours	Vehicle test officer (supervisory)
	-47°F	3 hours	Vehicle test officer (supervisory)
	-0°F to -20°F	3 hours	Passenger in UH1 helicopter

Participant Number 2

Foot Size	Ambient Temperature	Exposure	Activity
11EE	-27°F to -43°F	2 1/2 hours	Marching. Snow got inside boot top and had to be removed because of cold.

(8) Support and Balance. The two particpants in paragraph (7) above reported difficulties with support and balance. The one with size 11EE reported these difficulties only while skiing.

(9) Tread Wear:

a. Average tread depths before and after test period were as follows:

	Left			Right		
	Before	After	Wear	Before	After	Wear
Sole	.201 in.	.183 in.	.014 in.	.265 in.	.239 in.	.026 in.
Heel	.257 in.	.247 in.	.010 in.	.270 in.	.255 in.	.015 in.

(b) Average wear - .018 inches or approximately 1/64-inch.

(c) The instrument used to measure tread depths was designed for use on a flat metal surface. It is probable that some error was introduced because of the flexibility of the sole and the rounded, worn lugs on the sole.

(10) Comfort. Comfort data could not be analyzed because of the large number of test participants whose foot size did not correspond to the boot size.

6. Conclusion:

No substantial conclusions can be drawn due to the limited sample size and short test period. It is the opinion of this Center that the test item is not as durable as the Standard White Vapor Barrier Boot.

7. Recommendation:

It is recommended that the boot, with gauntlet and improvements in durability, be tested in a more extensive Engineer Design Test using an adequate sample of properly fitted soldiers in an arctic winter field environment of 6 months duration.

FOR THE COMMANDER:

R.E. Childs, Jr.

2 Incls
as

R. E. CHILDS, JR.
CPT, AGC
Adjutant

Copies furnished
CG, USATECOM, ATTN: AMSTE-BC, APG, MD 21005
CG, USATECOM, ATTN: USACDC LnO, APG, MD 21005

A. B..." SUITABILITY-COMPATIBILITY FO

U. S. ARMY ARCTIC TEST CENTER
APO SEATTLE 98733

BOOT SUITABILITY-COMPATIBILITY FORM

GENERAL: The test participant will complete this form at the end of each test day.

____

(NAME) (LAST) (FIRST) (MI) (DATE)

1. Which boot did you wear:

   Boot No. ____________

   I wore __________ pair(s) of ____________________ socks.
   (number) (type)

2. What was the outdoor temperature range? ________°F to ________°F

3. Describe in detail your activities while wearing the test boot: ____________

____

____

____

4. Were the boots comfortable? ______ Yes ______ No

   If no, explain ____

____

5. I encountered the following difficulties: ☐ None

   ☐ Stiff ☐ Too Cold ☐ Failure to hold binding

   ☐ Loose ☐ Tight ☐ Difficulty in mounting

   ☐ Too warm ☐ Mobility ☐ Boot got wet inside

   ☐ Because of:

   ☐ Perspiration ☐ Snow, ice ☐ Water

STEAC-MT-EN Form 311
8 Oct 70 (one time)

Incl I

Explain how snow, ice, or water got in the boot________________________

____

6.a. I wore the test boot in or on (vehicle) for________hours (and did what?)

____

6.b. I encountered difficulty in:

☐ Mounting and dismounting ☐ Foot comfort

☐ Leg and foot room ☐ Other________________

7. Did you have any problem donning or doffing the boot? ☐ Yes ☐ No

What type glove did you have on?________________________

8. Answer Yes or No:

a. Did the boot give good support?________________.

b. Did the boot give good balance?________________.

c. Did the boot provide good traction while walking on melting ice?________

d. Was the boot comfortable while traversing mountainous terrain?________

If no, explain________________________________

e. Did the boot slip at the heel?____________.

f. Does the boot need a "takeup" strap at the top?______at the ankle?______

g. Were any petroleum products spilled on the boots?__________.

9. The boot sustained damage (location, how, how much, and effect)__________

____

Was the damaged boot able to provide adequate insulation? ☐ Yes ☐ No

10. Examination of your feet revealed?________________________.

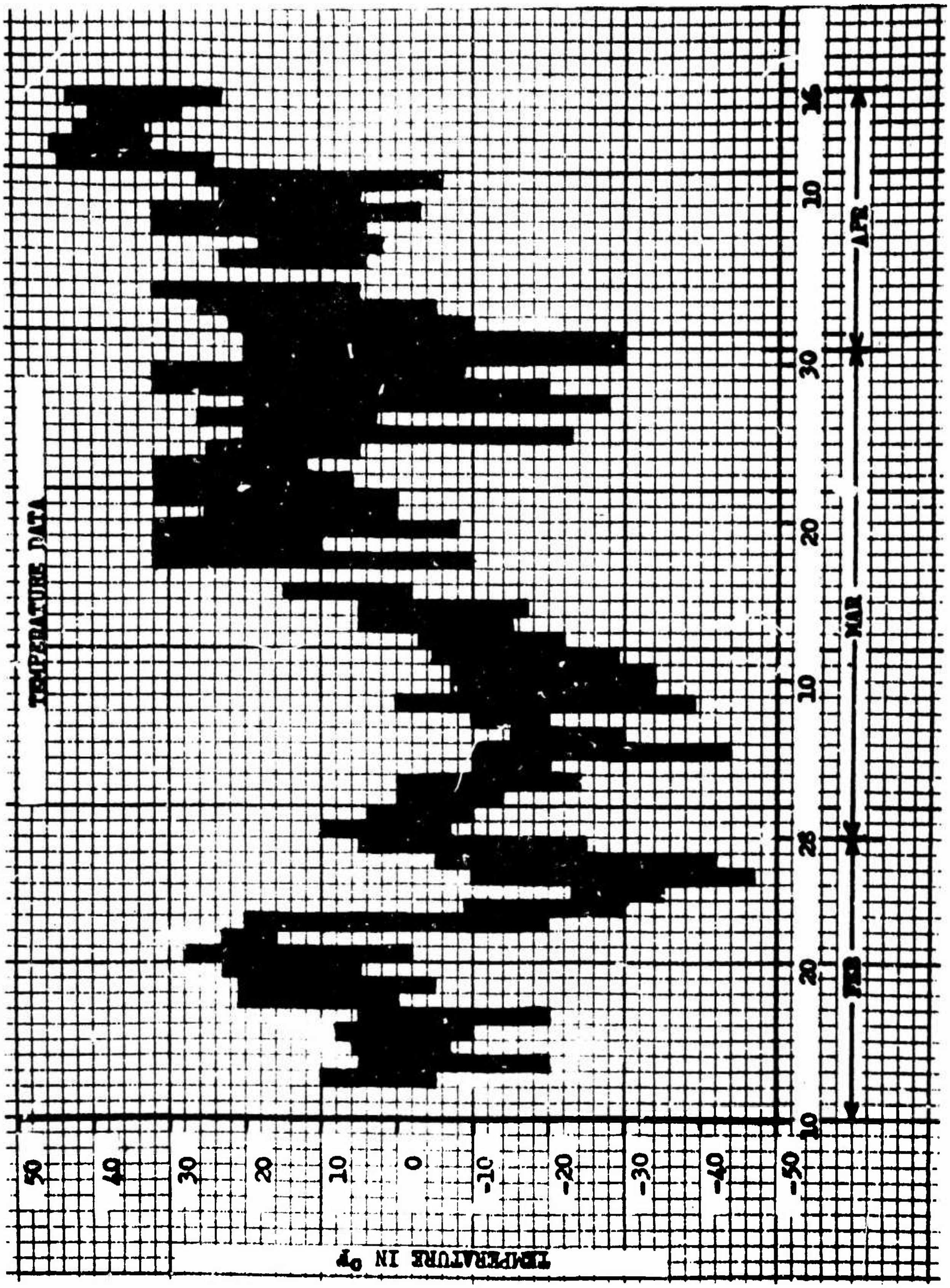
11. If you were subjected to sustained combat in temperatures of -20°F and above, which boot would you prefer to wear? _______White VB Boot _______Test Boot.

Why?____

I have the following comments:________________________________

____

____


TEMPERATURE DATA
TEMPERATURE IN °F
50
40
30
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10
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-10
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-30
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28
10
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16
FEB
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APPENDIX E

Letter Report of Evaluation of Boot, Lightweight, Insulated, Wellington Style

by

Headquarters, United States Army, Alaska

DEPARTMENT OF THE ARMY
HEADQUARTERS, UNITED STATES ARMY, ALASKA
APO SEATTLE 98749

ARACD

17 JUN 1971

SUBJECT: Report of Evaluation, Boot Lightweight Insulated, Wellington Style

Commanding General
US Army Natick Laboratories
ATTN: AMXRE-CCP
Natick, Massachusetts 01760

The evaluation report, subject above, is forwarded for your information and necessary action. Please note this report is in six parts: Parts I and II developed by Company O, 75th Infantry (Arctic Rangers), Parts III and IV developed by the 19th Aviation Battalion and Parts V and VI contain the overall conclusions and recommendations.

FOR THE COMMANDER:

1 Incl
as

C. H. PASKE, III
1LT, AGC
Asst Adjutant General

LIGHTWEIGHT INSULATED BOOT EVALUATION REPORT
Co O, 75th Infantry (Arctic Rangers)

I

General Data

1. The experimental boot was worn by the same five men during the test period and encompassed a total time of wear of 20 days per pair during the months of February, March and April 1971.

2. Each man wore a size 10 as his normal boot size.

3. Boots were worn with one pair of cushion sole socks.

4. Temperature ranges varied from +20°F to -50°F.

5. Boots were modified early in the evaluation to include the addition of a three to four inch cuff on the top capable of being closed with a Velcro fastener to preclude entry of snow into the boot.

II

Remarks

1. Boots were utilized in skiing, seven miles per person, and no difficulties were noted when utilizing the current standard A all terrain binding; however, with the advent of the cable binding a protrusion is needed on the heel to prevent the cable binding from slipping off. Note: A protrusion on the heel or a groove in the heel approximately 3/8" to 1/2" wide and 3/8" deep is required for use with the cable binding; however, a decision as to which (protrusion or groove) should not be made until boots incorporating these features have been evaluated.

2. Boots were utilized in snowshoeing a distance of four miles per person. No difficulties were noted.

3. Boots were utilized in walking a distance of four consecutive miles per person. No difficulties were noted.

4. Boots were utilized in 11 paradrops per person. No difficulties were encountered.

INCL 1

5. No boot damage or evidence of wear was noted.

6. The support of foot provided by the boot is excellent.

7. The weight of the boot is a definite advantage over that of the Vapor Barrier boot.

8. No slipping up and down was noted while walking, skiing or snowshoeing.

9. The ease of donning and doffing is a definite advantage over the Vapor Barrier boot.

10. The addition of the cuff is indispensable in keeping snow out of the boot; however, a drawstring closure may be more desirable than Velcro.

11. The lowest temperature at which the feet remain warm (moving and standing) was -20°F.

12. At -40°F one man's feet became numb. At -50°F one man experienced first degree frostbite after standing for a period of approximately one and one half hours.

19th Aviation Battalion

III

General Data

1. The experimental boot used by elements of the 19th Aviation Battalion stationed at Fort Wainwright, Alaska was evaluated primarily against compatibility for use with aircraft flight controls; i.e., rudder pedals and brakes.

2. Three pair of boots were provided to the 19th Aviation Battalion.

3. The boots provided to the 19th Aviation Battalion were rotated among aircrewmen that wore a size 10 as their normal boot size.

IV

Remarks

1. The boots are light and comfortable with the exception of tightness across the instep.

2. The feelings and sensations required to manipulate aircraft controls were far superior to the VB boot; however, the Air Force mukluks were still rated over the test boots.

3. Each person tested reported that their feet prespired more with the arctic test boots than with VB boots or Air Force mukluks.

4. The boot presented no problems walking but was rather stiff when in a sitting position manipulating aircraft controls.

5. The modification adding the extension to the top of the boot improved the boot from its original configuration; however, a drawstring to tighten the extension around the leg should be added to close the top to prevent heat loss or deep snow from entering.

6. The construction of the boot appears to be some type of sponge rubber with a latex or composition overspray. A general question was "If the outer layer is punctured, would the sponge layer underneath soak up moisture accordingly?"

7. Overall the Test Boot was rated superior to the VB boot in relation to flying activities. Of all aviators subjected to the test each one preferred the Air Force mukluks for flexibility, warmth and comfort over the Test Boot.

Overall Conclusions/Recommendations

V

Conclusions

1. The test boot offers a significant weight reduction over the standard Vapor Barrier boot.

2. The ease of donning and doffing is a distinct advantage.

3. The boots are compatible for use in walking, snowshoeing, the execution of paradrops and skiing; however, for skiing should, as previously stated, be modified to accept a cable type ski binding.

4. Lowest temperature worn with total comfort walking and standing, -20°F, is suspect. There may have been a sizing problem, although all test subjects allegedly wore a size 10 as their normal size, plus the fact that other persons not involved in the evaluation have worn the boots at -30°F to -40°F without discomfort.

5. A cuff on the top of the boot with a means of closing is required to prevent the entry of snow.

6. The boots are suitable for use by aircrewmen; however, are not the preferred item.

7. The boot is tight across the instep.

VI

Recommendations

1. The program be continued.

2. A variety of sizes be provided.

3. The heel be modified by the addition of a protrusion or groove to accept a cable type ski binding. Prototypes should be designed (not on the same pair of boots) incorporating these features and after test the decision be made as to the most desirable modification.

4. The boot be modified by the addition of a three to four inch cuff with a drawstring closing device to preclude the entry of snow.

5. Instep be slightly enlarged; however, not to the extent that heel slippage will occur.

APPENDIX F

Test Methods Used in Determining Physical Properties

Test	Method
Tensile, Modulus % Elongation	ASTM-D-412-66
Compression Deflection 25%	ASTM-D-1056-67T
Compression Set 50%	ASTM-D-1056-67T
Water Absorption:	
Vacuum Method	ASTM-D-1056-67T
Torsional Stiffness Test	ASTM-D-1053-65
Die B Tear	ASTM-D-624-54
Shore A Hardness	ASTM-D-2240-64T
Thickness	ASTM-D-1056-67T
Die C Tear	ASTM-D-624-54
Abrasion Index	ASTM-D-1630-61
Space Density	By water displacement
Water Absorption 6 inch head	Federal Std, No 601 Method 12411